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BUREAU OF PUBLIC ROADS

VOL. 15, NO. 1 MARCH 1934

THE HYDRAULIC FILL AT FOUR MILE RUN

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G. P. St. CLAIR, *Editor*

Volume 15, No. 1 March 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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A STUDY OF HYDRAULIC FILL SETTLEMENT

Reported by HENRY AARON, Assistant Highway Engineer, Division of Tests, Bureau of Public Roads

PORTIONS of the Mount Vernon Memorial Highway traversed tidal muck flats adjacent to the Potomac River and were constructed by placing a hydraulic fill of sand and gravel dredged from the river bottom. These fills aggregate approximately 2¾ miles in length and required the movement of about 3,500,000 cubic yards of material in their construction.

The quantity of fill material placed was considerably greater than was estimated originally to be necessary. Observations were made on the representative fill at Four Mile Run, to determine the factors responsible for the use of the excess material.

CONDITIONS INDICATED DESIRABILITY OF A POROUS FILL MATERIAL

The general location of the improvement and the original soil profile on the center line of the road are shown in figure 1. The profile consists of a layer of soft muck 10 to about 30 feet thick resting on a firm sand foundation and is covered with about 3½ feet of water at high tide.

The original design for the fill is shown in figure 2. A sandy gravel was to be used to form a fill 100 feet wide at the top, at an elevation about 10 feet above mean sea level and sloping to the surface of the muck at the rate of 4 to 1.

Porous fill material was specified for several reasons: (1) It furnishes high stability throughout the fill, and the fill is not jeopardized even by total saturation of its base; and (2) when the muck underlayer is compressed by the superimposed fill water can escape freely through the porous fill and settlement of the muck takes place quickly.

Quick fill settlement was desired primarily because of the necessity for constructing the pavement on the fills as soon as possible. However, the expedited settlement of the fills has a deeper and more important significance in regard to fill stability.

As the muck layer consolidates, its resistance to lateral flow or sliding increases. The more quickly the consolidation of the under soil occurs, the more rapidly does the factor of safety against failure of the fill due to sliding of the under soil increase. Danger of fill failure due to lateral flow of the under soil diminishes rapidly after the construction of fills of porous materials has been completed. There is not the same assurance of increased stability with fills of relatively impermeable materials. The consolidation of the compressible layer proceeds only as the contained water is squeezed out of the voids. If the water is removed as fast as it is released, the compression of the muck layer will take place in a more rapid and more uniform manner than it would if the water could not escape. With the passing of time fills comprised of porous material resting on a much less stable layer may support abrupt increases of load without danger of failure of the under soil by sliding. In contrast, the safe load capacity of fills of impermeable materials under the same conditions may not increase with age in the same manner.

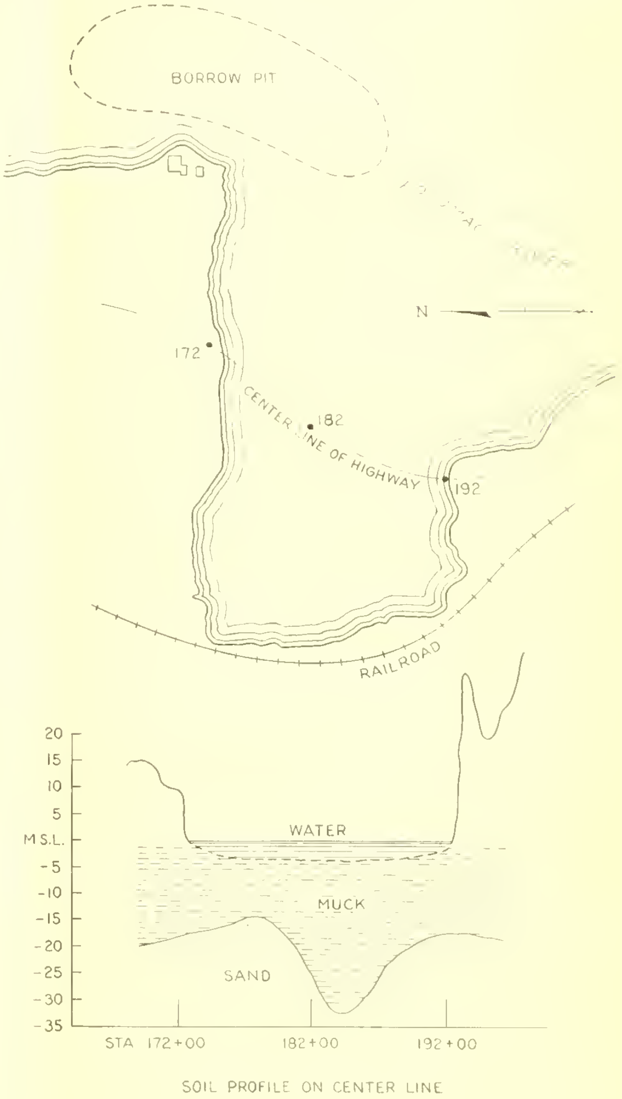

FIGURE 1.—PLAN AND SOIL PROFILE AT FOUR MILE RUN.

When a fill is constructed by the hydraulic method, large quantities of water are discharged with the fill material and the material must be such as to drain rapidly, otherwise it will require many years to become stable enough to support construction equipment. This was clearly illustrated while paving on Columbia Island on the same project. This island was made by pumping unselected material from the Potomac River during the process of channel deepening.[1] The fill had been built over 5 years before, but there were many places which would not support the weight of a man until artificial drainage was provided. No difficulties were encountered when paving over the fill described in this report, even though the pavement was placed within 2 years of the completion of the fill.

Borings made to locate a porous material for use in the fill disclosed a supply of sand and gravel within the range of dredging equipment at the location shown in

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[1] Public Roads, vol. 13, no. 4, June 1932, p. 57.

318888

Figure 2.—Fill Section as Designed and Character of Undersoil.

figure 1. This material was graded from fine sand to gravel 6 inches in diameter or larger and had an average loose weight of 101 pounds per cubic foot and a rodded weight of 110 pounds per cubic foot. Prospecting for a suitable fill material was done with a wash boring outfit mounted on a scow.

FILL CONSTRUCTED BY HYDRAULIC METHOD

The fill was constructed in two lifts as shown in figure 3, which shows also the progress of the work. The cross hatching shows the elevation through which the fill was raised by the two lifts but is not indicative of the quantity of material required in each operation. The total amount of material equals that for the cross hatched area plus that for the space between the bottom of the cross hatching and the broken line shown below. How this additional material was divided between the two lifts is not known.

The first lift was constructed by pumping material continuously into place to an elevation of about 5 feet through a single pipe line. The second lift was constructed in three sections as regards time of placement and two as regards the position of the pipe discharging fill material. From the north end of the fill to approximately station 186 the material for the second lift was pumped through two pipe lines spaced about 50 feet apart, one pipe discharging about 25 feet to the right and the other about 25 feet to the left of the center line as shown in figure 4. Figure 5 shows a view of the fill at this stage of the construction. The two pipe lines were moved close together at the center line, as shown in lower sketch of figure 4, for the construction of the remainder of the second lift.

During the construction of the second lift with the pipe lines separated 50 feet, sliding of large portions of the fill occurred at the two locations designated in figure 3. When the slides began cracks formed around the area adjacent to the discharge pipe and widened as the pumping continued. The fill settled vertically and displacement took place laterally. With the continuation of these phenomena mounds of soft river muck were forced up to a height of as much as 8 feet above the original river bottom thus disturbing the original muck layer for distances of several hundred feet from the center line. The pumping was continued until the lateral flow stopped and the fill reached the required height. Subsequently elevations were measured at regular time intervals in order to determine the rate at which settlement occurred.

Figure 6 shows a mound produced by the slides. A close-up of one of the mounds which shows the character of the displaced river bottom material after exposure to the atmosphere is shown in figure 7. Figure 8 shows the cross sections of the fill at four different locations as indicated by the borings.

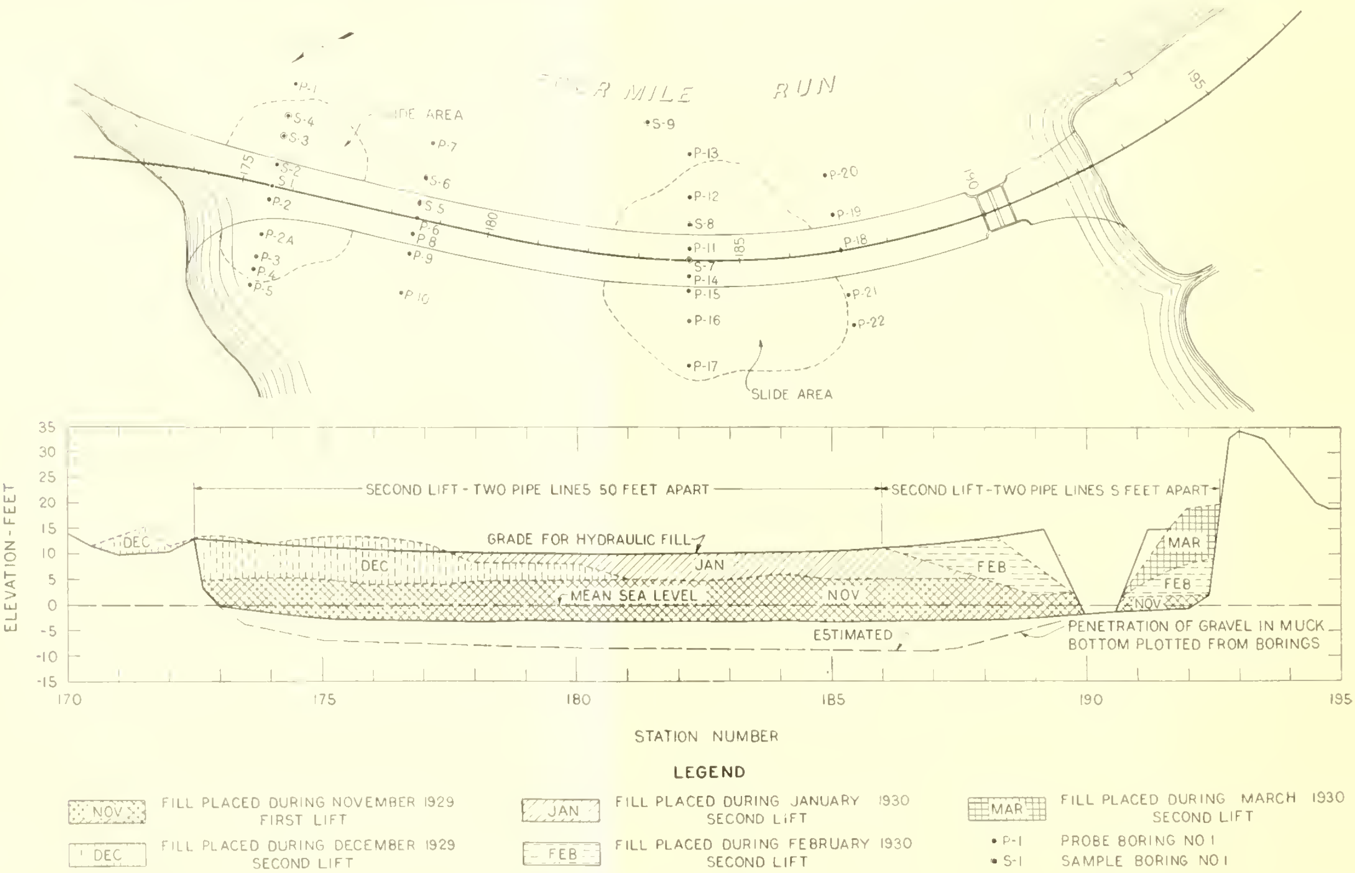
FOUR MILE RUN
SLIDE AREA
SLIDE AREA
P-1
S-4
S-3
S-2
S-1
P-2
P-2A
P-3
P-4
P-5
P-7
S-6
S-5
P-6
P-8
P-9
P-10
S-9
P-13
P-12
S-8
P-11
S-7
P-14
P-15
P-16
P-17
P-20
P-19
P-18
P-21
P-22
175
180
185
190
195
35
30
25
20
15
10
5
0
-5
-10
-15
ELEVATION - FEET
SECOND LIFT - TWO PIPE LINES 50 FEET APART
SECOND LIFT - TWO PIPE LINES 5 FEET APART
GRADE FOR HYDRAULIC FILL
DEC
DEC
JAN
FEB
MAR
FEB
NOV
NOV
MEAN SEA LEVEL
ESTIMATED
PENETRATION OF GRAVEL IN MUCK BOTTOM PLOTTED FROM BORINGS
170
175
180
185
190
195
STATION NUMBER
LEGEND
NOV FILL PLACED DURING NOVEMBER 1929 FIRST LIFT
DEC FILL PLACED DURING DECEMBER 1929 SECOND LIFT
JAN FILL PLACED DURING JANUARY 1930 SECOND LIFT
FEB FILL PLACED DURING FEBRUARY 1930 SECOND LIFT
MAR FILL PLACED DURING MARCH 1930 SECOND LIFT
• P-1 PROBE BORING NO 1
• S-1 SAMPLE BORING NO 1

Figure 3.—Location of Borings and Progress in Constructing Hydraulic Fill at Four Mile Run, Mount Vernon Memorial Highway.

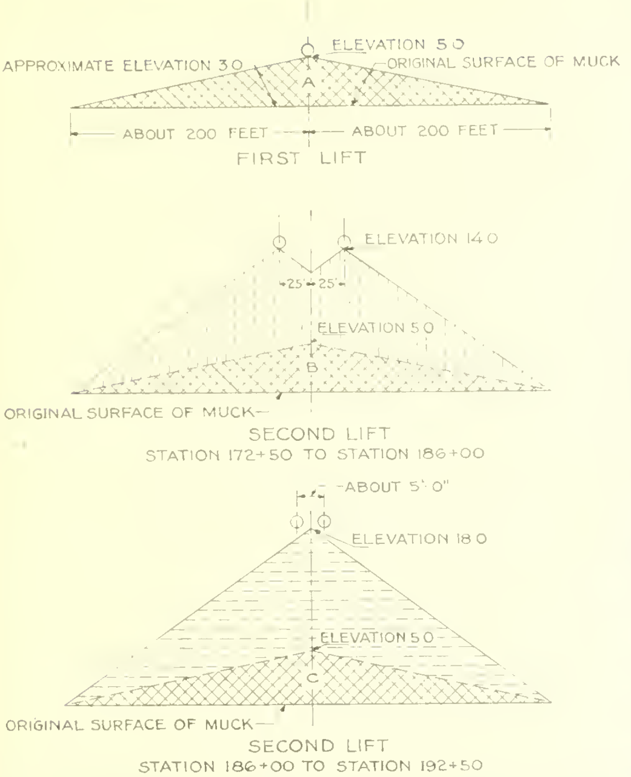

FIGURE 4.—LOCATION OF PIPE LINES AT VARIOUS STAGES OF CONSTRUCTION.

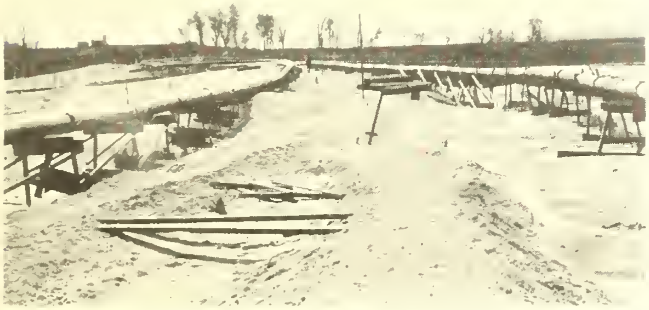

FIGURE 5.—DOUBLE PIPE LINE FOR PLACING SECOND LIFT.

METHODS OF DRILLING AND SAMPLING DESCRIBED

The location of the borings to determine the cross section of the fill and to obtain samples of the compressed muck layer are shown in figure 3. They were of two kinds, the "probe" borings designated as P-1, P-2, etc., and the "sample" borings designated as S-1, S-2, etc.

The "probe" borings were made by driving a 2-inch pipe through the fill material and soft under soil until firm foundation was reached. As the driving proceeded the material penetrated was washed up through the 2-inch pipe by water pumped through a 1-inch drill pipe. These borings indicated only the elevation of the bottom of the fill material and the bottom of the muck. A set-up of this boring equipment is illustrated in figure 9.

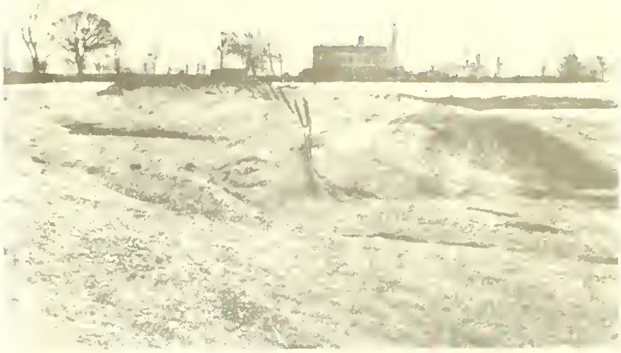

FIGURE 6.—LEFT SIDE OF FILL AT STATION 175+50 SHOWING AREA OF BULGED MATERIAL AND NATURE OF SLIDE. THE ROW OF STAKES IN THE FOREGROUND WAS ON THE SHOULDER LINE OF THE FILL BEFORE THE SLIDE OCCURRED.

FIGURE 7.—MATERIAL DISPLACED AND SHOVED UP BY SETTLEMENT OF FILL.

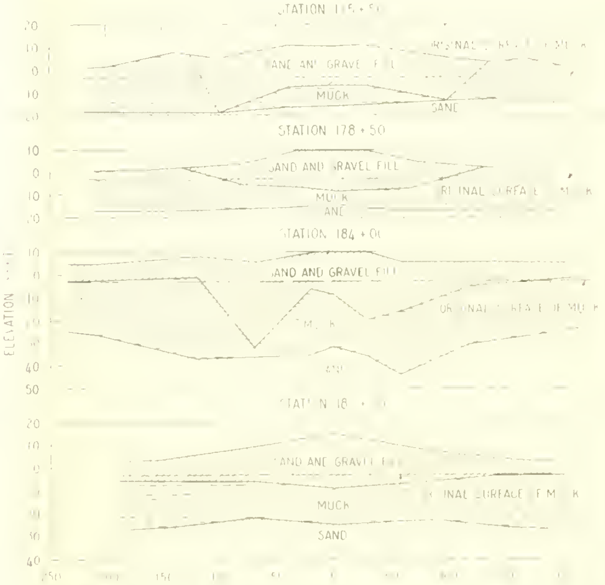

FIGURE 8.—CROSS SECTIONS OF FILL AS INDICATED BY BORINGS.

In making the "sample" borings a 4-inch pipe was used for the casing and a 2-inch pipe for drilling and washing in the same manner as for the "probe" borings. As the drilling proceeded cores of river-bottom material were obtained in an undisturbed state from different elevations in the muck layer.

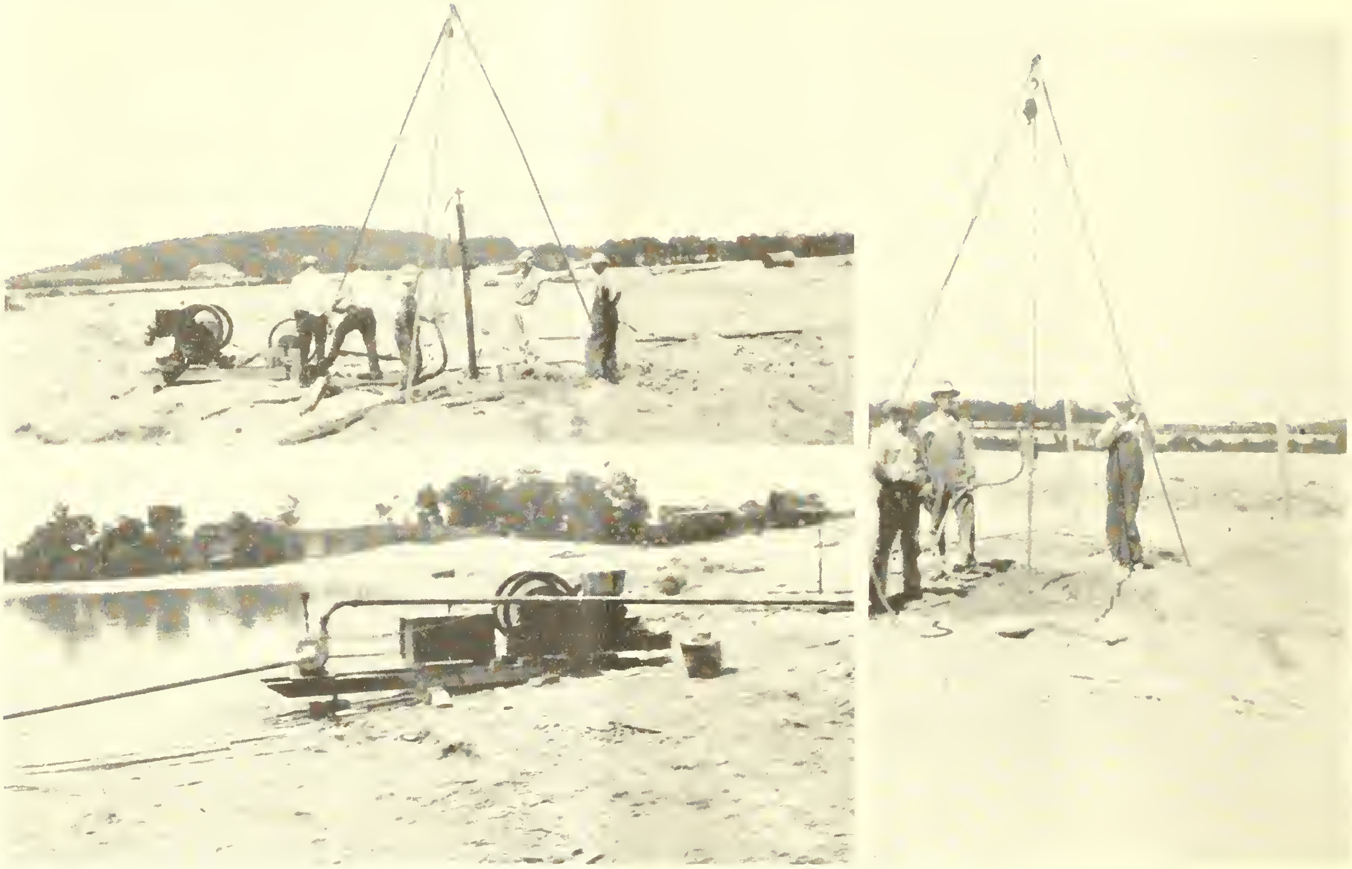

FIGURE 9.—UPPER LEFT APPARATUS FOR TAKING UNDISTURBED CORES. LOWER LEFT AND RIGHT APPARATUS FOR PROBE DRILLING.

The equipment used in driving and washing the casing is illustrated in figure 9.

The device for taking cores consisted of a section of 3-inch galvanized steel pipe about 15 inches long, sharpened at one end, and attached by a special coupling to a 1-inch pipe at the other. Inside the coupling was a check valve, specially designed as illustrated in figure 10 to prevent the loss of the core when the pipe was withdrawn.

The undisturbed samples were taken in the following manner:

The 4-inch casing was first thoroughly cleaned of all the material penetrated, after which the coring device was lowered through the casing and pushed down into the river-bottom material slowly and without twisting. The air and water entrapped by the soil entering the device escaped through the check valve. When the resistance to further penetration indicated that the device was filled with soil, it was turned through two revolutions and then pulled up slowly. The tube containing the soil core was next uncoupled, sealed with paraffin, and labeled. Figure 11 shows two cores sealed with paraffin and the sampling device for obtaining these cores.

At depths other than those at which the cores were taken, samples of the material washed up through the casing were obtained and placed in glass jars of 1-quart capacity.

The elevations from which both cores and samples were obtained in the "sample" borings are shown in figure 12, which shows also the character of the material penetrated as identified in the field. Sample boring S–9 (see fig. 3) was taken 264 feet from the center line at a point outside of the fill area and is intended to represent the muck in its natural uncompressed state. Even at this distance some disturbance of the muck occurred although no fill material was present.

The wash boring samples were tested in the subgrade laboratory of the bureau at Arlington, Va. The cores were tested at the Massachusetts Institute of Technology as a part of a cooperative research on subgrade materials.[2]

ANALYSIS OF SAMPLES DISCLOSES CHARACTERISTICS OF THE RIVER-BOTTOM MATERIALS

The results of the standard laboratory tests[3] performed on the samples of soil collected in the wash boring are shown in table 1 and the results of tests[4] on the core materials are shown in table 2. Table 2 shows also the moisture content of the samples in the natural state.

The test results (table 1) show that the sand belongs to the good A–3 soil group and the mucks (tables 1 and 2) belong to the A–8 group. The wash-boring samples (table 1) had lost the finer portion of muck

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[2] These tests were carried out under the supervision of Arthur Casagrande, formerly research assistant of the Bureau of Public Roads, stationed at the Massachusetts Institute of Technology. Mr. Casagrande aided in drawing up the specifications for drilling and sampling.

[3] These tests were carried out according to the Procedures for Testing Soils for the Determination of the Subgrade Soil Constants, Public Roads, vol. 12, no. 8, Octobe 1931.

[4] The tests on the core material were performed on the materials before they had dried out. The procedures for making these tests are described in Research on the Atterberg Limits of Soils, Public Roads, vol. 13, no. 8, October 1932.

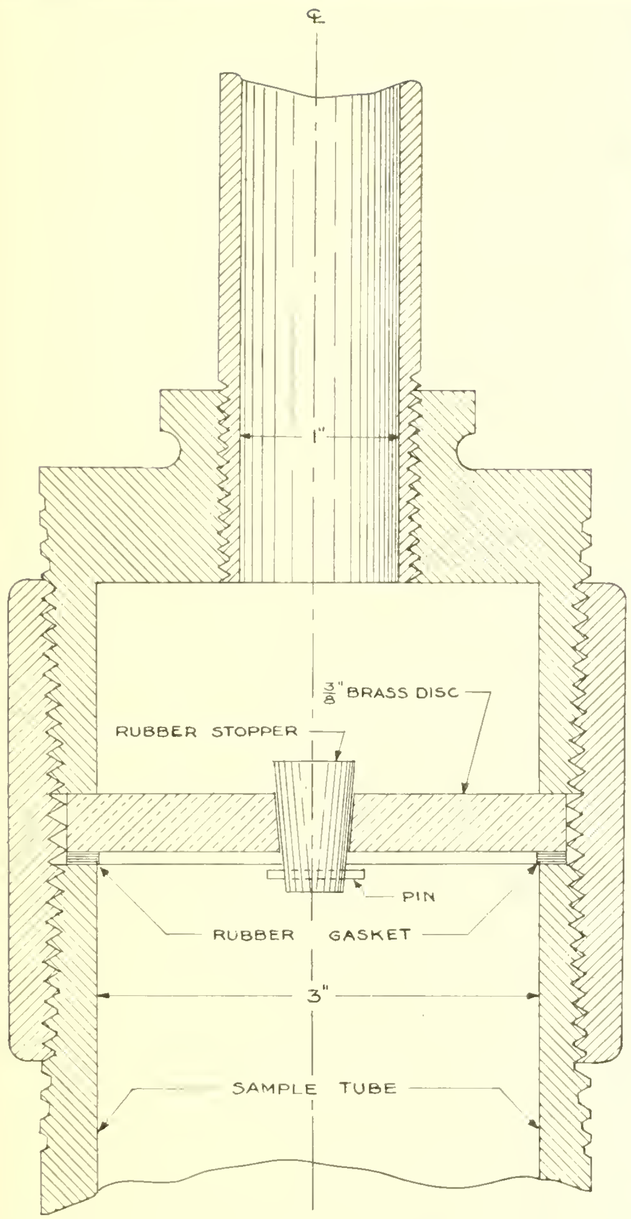

Figure 10.—Details of Check Valve Sampling Device.

due to the method of sampling. The samples as collected have lower liquid limits, lower plasticity indexes and higher shrinkage limits than the corresponding samples of muck (table 2).

The test results on the wash-boring samples (table 1) are more uniform than the results on core samples. There is indication that the variation in the results on cores is due to the presence of ultra fine material which was carried away in suspension in wash-boring or to some electrolytic property destroyed in taking the wash-boring samples.

Regardless of the cause of the difference, there remains the fact that the sand and muck samples of table 1 are similar to the materials used in building Columbia Island[5] which was constructed of river bottom material pumped from the Potomac River during the process of channel deepening. The wash-boring samples are representative of the material in fills constructed of muck placed by the hydraulic method and the core samples are representative of the under muck layers in place.

Figure 11. Sampling Device for Obtaining Undisturbed Cores and Two Samples Sealed With Paraffin.

Table 1. *Results of laboratory tests performed on samples obtained in wash boring. Sample locations are shown in fig. 12*

Boring no.	Sample no.	Mechanical analysis[1]: Particles larger than 2 millimeters	Particles smaller than 2 millimeters: Coarse sand, 2-0.25 millimeters	Fine sand, 0.25-0.05 millimeter	Silt, 0.05-0.005 millimeter	Clay, smaller than 0.005 millimeter	Colloids, smaller than 0.001 millimeter	Physical characteristics of material passing no. 40 sieve: Liquid limit	Plasticity index	Shrinkage: Limit	Shrinkage: Ratio	Moisture equivalent: Centrifuge	Moisture equivalent: Field
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*				
S-1	6	7	24	8	27	41	14	44	15	29	1.5	41	36
S-2	4	5	9	3	30	58	24	53	21	31	1.5	52	39
	5	(2)	(2)	(2)	(2)	(2)	(2)	118	0	66	.8	109	111
S-4	1	6	13	12	34	41	18	72	8	40	1.2	69	57
	2	1	66	24	3	7	3	19	0			7	21
S-5	7	6	5	11	52	32	9	61	5	40	1.3	58	74
S-7	11	1	7	4	33	56	25	53	24	33	1.5	54	42
	12	2	8	9	49	34	16	59	18	41	1.3	55	54
	13	1	9	23	40	28	14	52	17	40	1.3	46	49
	14	2	6	12	49	33	13	52	17	37	1.3	52	48
S-9	9	0	4	7	54	38	20	63	41	37	1.3	66	52
	10	0	0	4	47	19	21	62	22	37	1.3	69	54
(4)	3	0	1	5	59	35	16	55	10	37	1.3	66	51

[1] Percentages of material larger than 2 millimeters based on total sample, other percentages based on sample exclusive of this size. Percentage smaller than 0.005 millimeter includes percentage smaller than 0.001 millimeter.
[2] Organic matter.
[3] Tends to waterlog.
[4] Sample taken from surface of muck at left of station 1754+50.

According to table 2 the mucks comprising the under soil have liquid limits varying from 62 to 132 and exist in place with moisture contents varying from 76 percent

Table 2. *Results of laboratory tests performed on cores. Locations of cores are shown in fig. 12*

Boring no.	Core no.	Moisture content, natural state	Liquid limit	Plasticity index	Shrinkage limit
S-2	2	76	77	38	[illegible]
S-4	1	108	103	49	[illegible]
S-5	3	120	128	66	[illegible]
	1	107	131	61	[illegible]
S-6	5	125	132	69	[illegible]
S-7	8	64	89	18	27
	9	105	96	47	[illegible]
	10	116	112	[illegible]	32
S-9	6	79	62	30	29
	7	117	79	36	[illegible]

These cores were very nonuniform and were not suitable for compression tests. Therefore, they are not considered in the analysis of the test data.

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[5] Public Roads, vol. 13, no. 4, June 1932, p. 57.

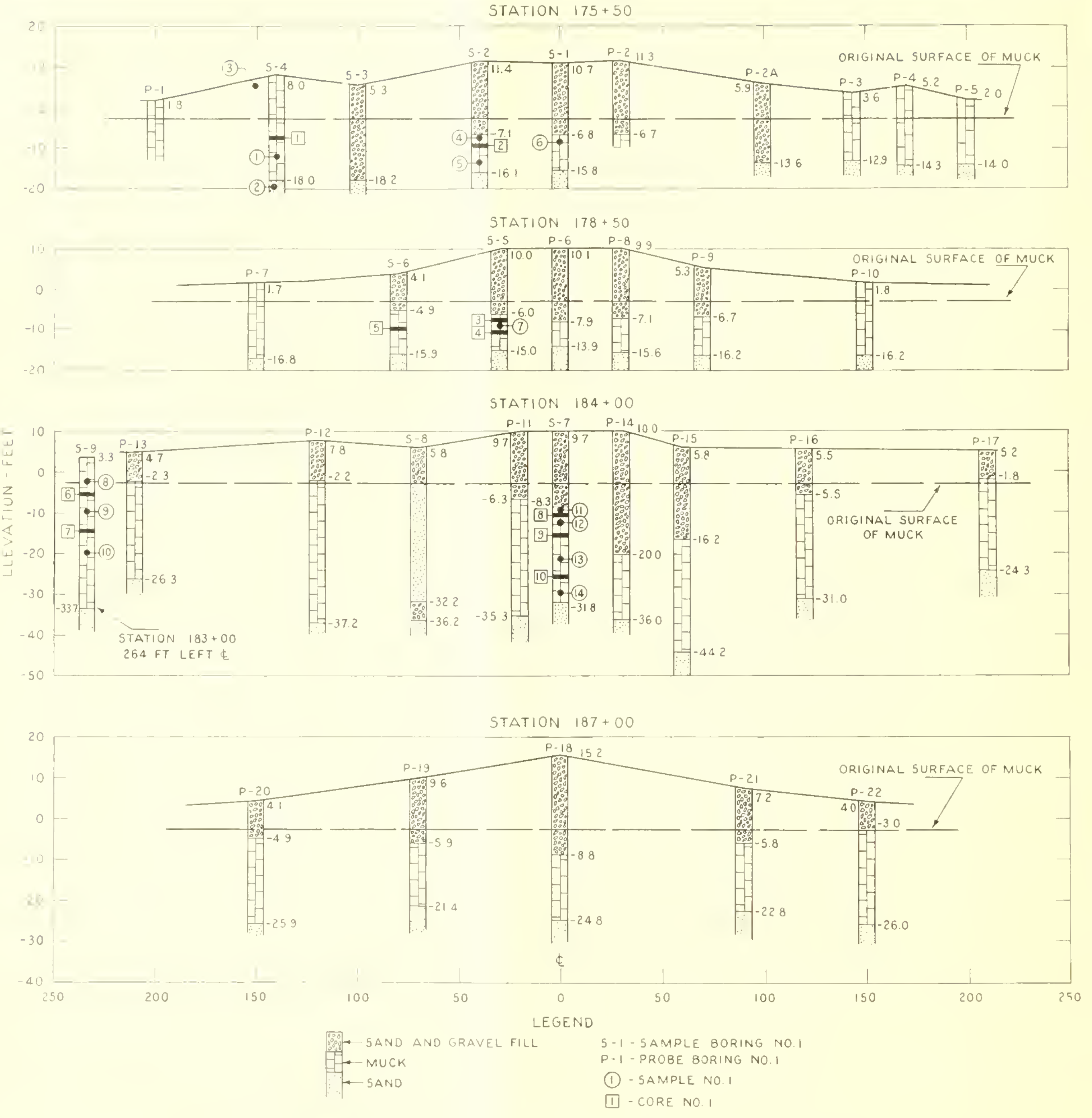

Figure 12.—Results of Borings in Hydraulic Fill at Four Mile Run.

to 125 percent of the weight of the dry soil. On the basis of relative volumes, for every part of solid soil material (with a specific gravity of 2.6 in this case) there are from 2 to 3¼ parts of water. The stable sand layer, in contrast, is not likely to contain more than 0.6 part of water by volume to each part of solid material. The significance of such differences in moisture content with respect to the relative stability of sands and mucks has been discussed previously in Public Roads.[6]

SUBSURFACE MOVEMENTS OF FILL OCCURRING DURING CONSTRUCTION DISCLOSED BY BORINGS

The cross sections of the fill as shown by the borings plotted in figure 8 disclose the following:

1. Where no slides occurred, as at station 187, the fill material penetrated into the muck fairly uniformly throughout the cross section. The greatest penetration occurred in the center, under the greatest weight of fill, and the penetration diminished toward the sides as the fill feathered out. The contour of the lower surface of the fill at station 187 is, in a general way, similar to that of the upper surface but in a reversed

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[6] Stabilization by drainage of muck and sand fill. Public Roads, vol. 13, no. 4, June 1932, pp. 57–60, inclusive.

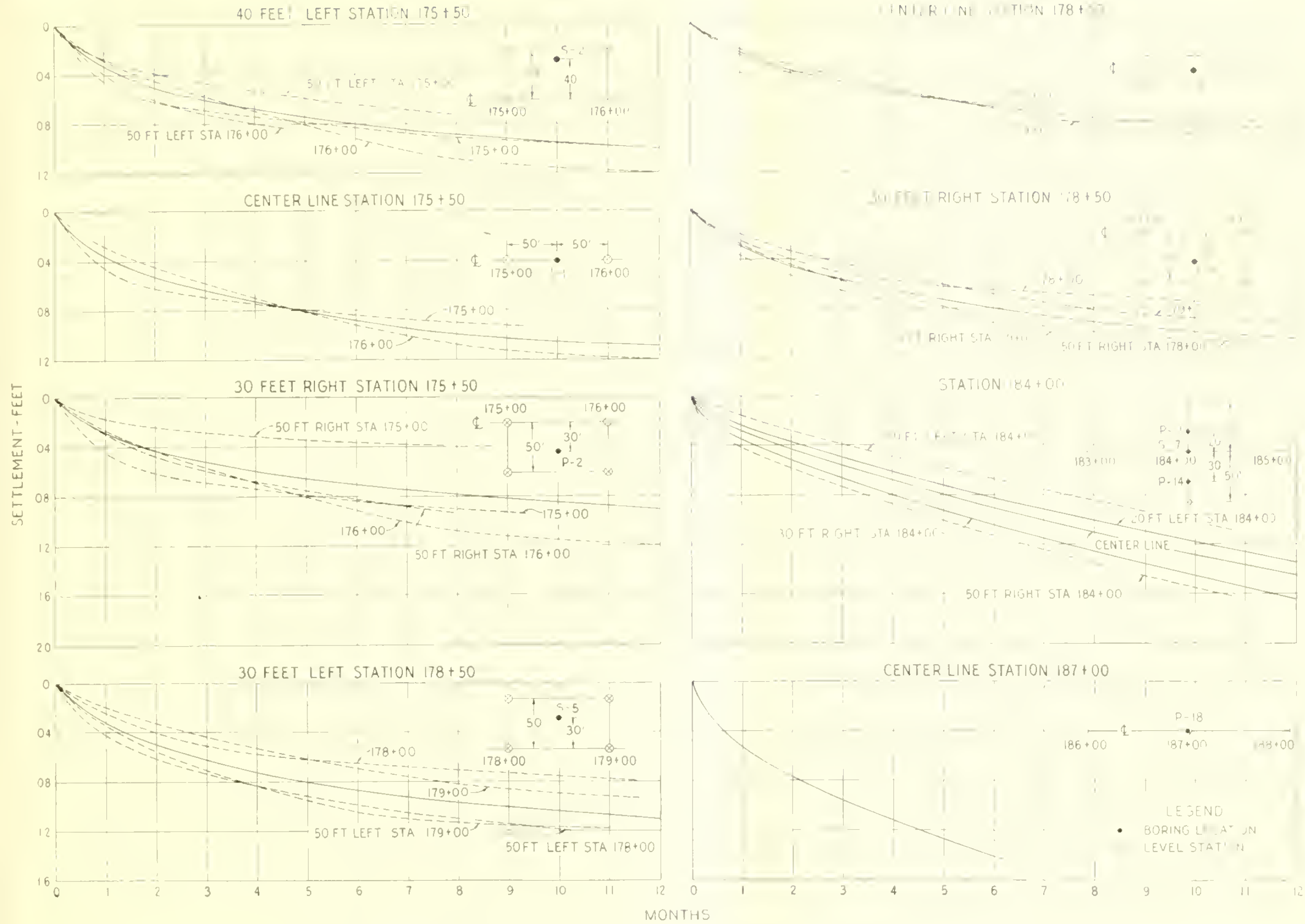


Figure 13.—Measured and Interpolated Settlements of Fill.

position. At station 178+50, where no abrupt slides were observed during construction, the penetration was very similar to that at station 187, but lateral flow is indicated by the position of muck surface 4 feet above its original position at the outer limits of the fill.

2. At station 175+50, where the muck varied from 11 to 13 feet deep, the fill penetrated to a depth of 4 feet in the portion between the shoulder lines of the roadway. On both sides, however, at a distance of about 100 feet from the center line, the fill displaced the entire depth of the muck and rested on the firm underlying sand. The displaced muck was pushed up in a mound 8 feet high at a distance of about 150 feet from the center line (fig. 6). This action trapped muck beneath the roadway. The greatest amount of upheaval occurred on the left side, where the sand layer is at a lower elevation.

3. The greatest amount of sliding and the most irregular penetration occurred at station 184 where the depth of muck ranged between 28 and 41 feet and the penetration of the fill varied from 5 feet at the center to 29 feet at 70 feet left of the center line and 17 feet at 30 feet right of the center line. Unlike the fill at station 175+50, at no point did the fill at station 184 penetrate the entire depth of the muck. However, at this place the layer of muck is considerably thicker than at station 175+50 and the surface of the sand is very irregular. To some extent the lower surface of the fill parallels the surface of the sand, especially at the right half of the section.

SETTLEMENT OF FILL DETERMINED FROM LEVEL READINGS

Settlement of the fill during the first 12 months of its existence was determined by levels, taken periodically, on stakes set in the fill on the center line and 50 feet to the right and left of the center line. The stakes were destroyed during the grading and shaping operations at the end of 12 months and no additional levels were taken until the pavement was laid about 20 months after the construction of the fill. Since that time levels have been taken periodically on the pavement. Since no readings were obtained during an interval of 8 months and there was a possibility of error in transferring elevations from the stakes to the pavement, these elevations are not discussed in this report.

Only 10 borings were located within 50 feet of the center line. The locations of the borings and of the level stations do not coincide. Level points were located at the even stations about 5 months before plans for boring were made. The borings were located at points in the fill which would give the most reliable information concerning the movements of the fill material, according to observations during construction.

Figure 13 shows graphically the settlement at drill holes and at level stations in the vicinity of the holes. The sketch with each graph shows the relative positions of the level stations. The broken lines represent the observed settlements as measured with the level while the solid lines show the settlements at the drill hole as

Table 3.—*Summary table of settlement, loads, muck thicknesses, and characteristics of muck layers*

Station	Location	Sample identification			Moisture content		Gravel thickness	Superimposed load [1]	Thickness of muck			Settlement at—		
		Boring no.	Core no.	Sample no.	In place	Liquid limit			Original	Time of borings	Difference	1 month	6 months	12 months
					Percent	*Percent*	*Feet*	*Kg per sq cm*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
175+50	40 feet left	S-2		4		53								
			2		69–76	77	18.5	0.8496	13.1	9.0	4.1	0.34	0.80	1.00
				5		118								
	Center	S-1		6		44	17.5	.8020	12.8	9.0	3.8	.35	.88	1.08
	30 feet right	P-2					18.0	.8308	12.1	8.4	3.7	.28	.70	.90
178+50	30 feet left	S-5	3		120	128								
				7		64	16.0	.7376	12.0	9.0	3.0	.32	.87	1.10
			4		107	131								
	Center	P-6					18.0	.8065	10.9	6.0	4.9	.23	.68	.85
	30 feet right	P-8					17.0	.7690	12.6	8.5	4.1	.29	.80	1.06
184+00	20 feet left	P-11					16.0	.7315	32.3	29.0	3.3	.23	.82	1.35
	Center	S-7		11		53								
				12		59								
			9		105	96	18.0	.7984	28.8	23.5	5.3	.28	.91	1.45
				13		52								
			10		116	112								
				14		52								
	30-feet right	P-14					30.0	1.2058	33.0	16.0	17.0	.35	1.05	1.64
187+00	Center	P-18					24.0	1.1105	21.8	16.0	5.8	.52	1.40	

[1] Computed from gravel thickness as disclosed by borings made about 6 months after completion of fill.

[2] All organic matter.

interpolated from the measured settlements at the level stations.

The level points on the center line at stations 184 and 187 coincide with the boring locations. Therefore, for station 187 the solid line represents the actual measured settlement. At station 184 the center-line stake was destroyed soon after construction of the fill and the settlement at this point was interpolated.

FILL SETTLEMENT AND LATERAL FLOW DISCUSSED

Table 3 presents the settlement at the 10 boring locations at 1, 6, and 12 months after construction of the fill, together with the fill load, thickness of muck, and information on the character of the muck soil. The data for this table were taken from tables 1 and 2 and figures 12 and 13. The superimposed loads were computed on the basis of full hydrostatic uplift effective below zero elevation.

The difference between the thickness of the muck layer prior to construction and that at the time of the borings represents the combined effect of lateral flow and 6 months compression under load. This difference varies from 3 feet to 17 feet (table 3). However, the total measured settlement for the 6-month period preceding the boring operations ranges from a minimum of 0.7 foot to a maximum of 1.4 feet. Therefore, the reduction in thickness of the muck layer was due largely to the lateral flow occurring during construction.

The variables apt to influence lateral flow are character of soil, soil profile, load, original thickness of muck layer, and construction methods. The construction procedure at station 175+50 was the same as that at station 184, and the behavior of the fill at these stations may be compared with respect to the other variables. A study of table 3 and figure 8 discloses no clear cut relationship existing between the amount of lateral flow and the above factors. However, it is true in a general way that, at station 184, where the lateral flow was of greater intensity, the natural moisture contents and liquid limits of the muck layers, the variations in the soil profile, and the original thickness of the muck layers were greater in amount than at station 175+50. On the other hand, considering station 184 by itself, these general relations do not explain the variations which have occurred.

The loads shown in table 3 have no significance as to cause of lateral flow since the variation in load is the result of lateral flow. It will be noted that the heaviest loads in any section occur at the points where the abrupt slides took place. No abrupt slides occurred at stations 178+50 and 187 where the second lift was placed in two layers with a period of time intervening between layers. This indicates that the rate of application of the load is more important in affecting fill movements than is the total load as disclosed by the borings.

The factors which are apt to influence the amount and rate of fill settlement are characteristics of the muck layer, thickness of the muck layer, and the load superimposed on the muck layer. In this case the thickness of the muck layer at the time of the borings seems the logical value to use since all the lateral flow took place during construction or continued only a brief time after construction.

From table 3 and figure 13 it will be observed that there is very little difference in the amount and rate of settlement at stations 175+50 and 178+50 although the moisture contents and liquid limits of cores no. 3 and no. 4 indicate a much more unstable soil at station 178+50 than at station 175+50 which is represented by core no. 2. It appears that a large variation in soil properties as disclosed by these tests may have little influence on settlement.

Neither the amount of superimposed load nor the thickness of the muck layer shows any relation to the amount and rate of settlement. The loads at stations 175+50 and 178+50 are generally higher than on the center line and 20 feet left of center line at station 184 but the settlement after 12 months at the latter station is greater in amount. However, at the latter station the layer of compressible muck is more than twice as thick. At all points except station 187 the settlements for the first month are practically the same in amount. Furthermore, at 6 months the settlement on the center line at station 187 is much greater than that at 30 feet right of station 184, while the thicknesses of the muck layers are equal and the loads differ only by 0.1 kilogram per square centimeter.

The foregoing discussion shows that no consistent relationships exist between the amount and rate of settlement as measured and any one of the individual influencing factors of load, thickness of muck layer and characteristics of muck layer. These variables seem to be interdependent in influencing settlement. The compression test discloses, quantitatively, the combined effect of the several variables and it was decided to investigate the results of such tests.

COMPRESSION TESTS DISCUSSED IN A SUPPLEMENTARY REPORT

Extensive original research had to be performed in connection with analyses of the compression test data as such, before it was possible to explain the behavior of the fill at Four Mile Run. It is felt that a complete description of this work should be presented in a separate report. This supplementary report shows conclusively that the differences in moisture content of the muck undersoil (table 2) and the difference in settlement characteristics (fig. 13) are not the result of haphazard accident but, instead, are entirely in accordance with well-defined physical laws which control the consolidation of muck deposits. It is demonstrated that proper analysis of the compression test data furnishes excellent means for estimating the amount and speed of settlement of loaded soil layers.

SUMMARY

The effect of the principal construction and soil variables upon the fill movements just discussed may be briefly summarized as follows:

1. No consistent relation was found to exist between the arrangement of the pipe outlets and the extent of lateral flow. It is true that no slides occurred during the placing of the entire first lift or the placing of the second lift at station 187 when the material was discharged along the center line. In contrast, sliding did occur during the placing of the second lift at stations 175+50 and 184 when the double pipe line arranged as in figure 4 was used. But slides occurred also during the construction of two other fills on this highway where the muck was over 40 feet deep, although a single pipe line discharging on the center line was used.

2. The slope of the fill material during construction seemed to be important. This is not surprising since theoretically it is possible to make the slope of fills so small that lateral flow of even the softest of undersoils may be prevented. In this case no appreciable lateral flow occurred during the placing of the first lift, which had very flat side slopes of 25 to 1. The second lift was placed with a much steeper slope of 10 to 1. It is possible that had the slope of 25 to 1 been used throughout the second lift the sliding which occurred in certain places would have been prevented.

It seems that the softer the muck, the deeper the muck and the more sloping the surface of the sand bed beneath, the more tendency there will be for the muck to displace laterally.

Use of gentle slopes and placement of fill in thin layers seem to furnish the best possibilities for reducing sliding. In case sliding starts, it seems that shutting down the pumps temporarily, if there is no support for extension of pipe lines for continuing the fill ahead, is the most logical procedure. Consolidation of muck under the fill already placed will then proceed and increase the resistance of the muck to further sliding while the force productive of sliding remains constant.

3. The depth of the muck and the slope of the firm sand bed beneath seemed to exert some influence. The most extensive lateral flow occurred at station 184 where the greatest depth of muck and the most irregular surface of the underlying sand were found. However, no sliding occurred at station 187 where the layer of muck was originally over 10 feet thicker than at station 175+50 where sliding did occur.

4. The manner in which the second lift was placed may account for the slides which occurred at stations 175+50 and 184 and the absence of slides at stations 178+50 and 187.

At stations 175+50 and 184 where the entire second lift was constructed in a continuous operation the entire additional fill load was imposed upon the soft undersoil before adjustment took place.

At stations 178+50 and 187 where the second lift was constructed in two layers, the muck had an opportunity to consolidate under the load of the first layer before the second layer was imposed.

It was observed, during the construction of another fill in a location where the mud had a minimum depth of 40 feet, that when sections of the fill slid out laterally in a manner similar to that described in this report, the movement stopped soon after the pumps were shut off. When pumping was resumed after being shut down for about 2 days, a considerable amount of fill could be placed before more sliding occurred.

FROST HEAVE IN HIGHWAYS AND ITS PREVENTION

Reported by Henry Aaron, Assistant Highway Engineer, Division of Tests, Bureau of Public Roads

FROST ACTION affects road surfaces differently, depending on the type of surfacing. Rigid pavements are heaved and crack in excessive amounts but usually settle back in place after the frost leaves the ground. Successive heaves are often sufficient to break up long slabs of the thinner pavements to such an extent that replacement is required. In semirigid pavements the cracking and breakage due to one period of frost may require considerable patching, if not replacement. Low-type wearing courses, such as gravel, are often entirely lost after one season, the gravel mixing with the soft undersoil without furnishing stability. Figures 1 and 2 are examples of damage resulting from frost action.

When heave occurs abruptly there results a hazard to traffic. It is not uncommon for short sections of pavement to heave 10 or 12 inches above the adjacent surface, thus becoming an obstruction capable of causing fast-moving vehicles to leave the road. Examples of such heaves are shown in figure 3.

Rigid and semirigid pavements may adjust themselves during thaws so that traffic is carried without resorting to special construction. Frost heaved sections of gravel roads are apt to become soupy mud, impassable to any type of traffic during thaws. Figure 4 is an example of such a condition. These short impassable sections are sufficient to render the entire highway unsuitable for traffic for a period of several weeks during the spring and thus tend to isolate the towns located along the highway. Those who dare to venture forth usually require assistance in getting out of the mud before they get very far.

Therefore, aside from the large maintenance costs which arise from frost failures there is a heavy economic loss inflicted on the users of these highways.

PURPOSE AND SCOPE OF REPORT

Prevention of the harmful effects of frost action has been a major problem in constructing and maintaining roads in climates where severe freezing occurs. The heaving produced in various types of soils which form the foundation for road surfaces has been studied extensively, both in the laboratory and in the field. The results of these studies and the theories developed have been discussed in numerous published reports. Many types of remedial treatments have been installed in locations subject to frost heave by different engineers.

To correlate the various methods employed by different engineers, the Bureau of Public Roads with the cooperation of the highway departments of Minnesota, Wisconsin, and Michigan, conducted a survey during the period from 1928 to 1933 to determine for specific cases (1) method of treatment used (2) its performance under service conditions, and (3) the physical properties of the subgrade soils in the location and their arrangement in the soil profile. This report is the result of observations by the author, supplemented by information from the engineers and maintenance superintendents in the respective States. The following aided in planning and conducting the survey and furnished most of the photographs used in this report: A. Seifert and S. L. Taylor, district 4, United States Bureau of Public Roads; F. C. Lang, L. L. Allen, and C. K. Preus of the Minnesota Department of Highways; A. C. White, Mower County, Minn.; E. B. Tourtellot, Wisconsin Highway Commission; H. F. Janda, University of Wisconsin; and A. C. Benkelman, Michigan State Highway Department.

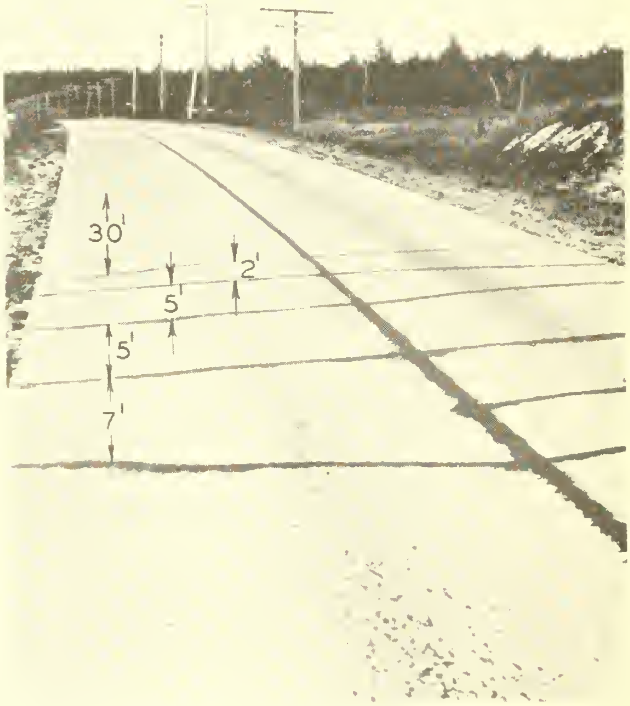


FIGURE 1.—CRACKING IN CONCRETE PAVEMENT DUE TO FROST HEAVE.

No attempt is made in this report to explain the physics or mechanics of frost heaving. It is intended, primarily, as an exposition of methods used to prevent harmful frost action and the results of these methods. In order to interpret properly the results of the various methods, it is important to know the characteristics of the different subgrade soils which make up the soil profile in the location where they were used. Before considering the results of the preventive measures, it is advisable to discuss the different soil profiles found in this survey and their influence on heaving.

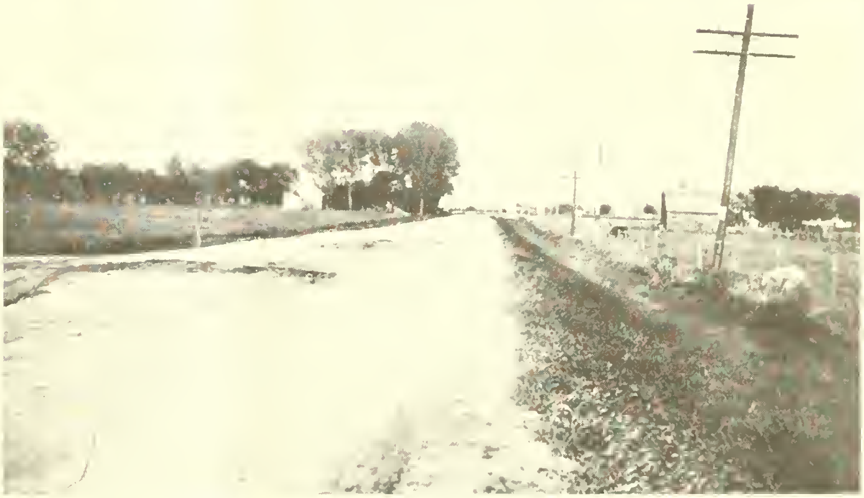
THE SOIL PROFILE INFLUENCES HEAVING

In many sections of the country a road surface rarely rests on a uniform subgrade for any great distance. This is due to two reasons:

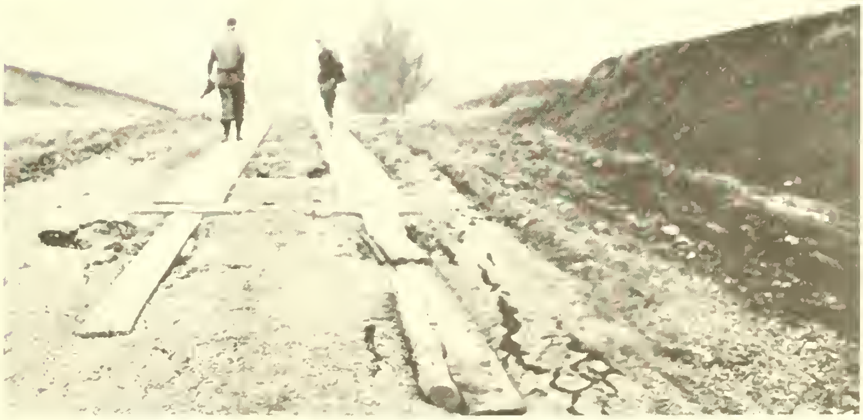
(1) The grade line frequently intersects a number of layers of the soil profile depending on the depth of cuts, and the several layers, often differing in their physical characteristics, will each in turn form the subgrade of the road.

(2) An individual soil layer may possess such variable characteristics as—

A Bituminous Surface Damaged by Frost Action.



Effect of Heaving on a Gravel Road.



Heaved Gravel Road at Beginning of Thawing Period. Planks Are Necessary to Prevent Miring.

Figure 2.—Examples of Typical Heaving.

(*a*) Pockets of soil material differing greatly in properties from those of the remainder of the layer.

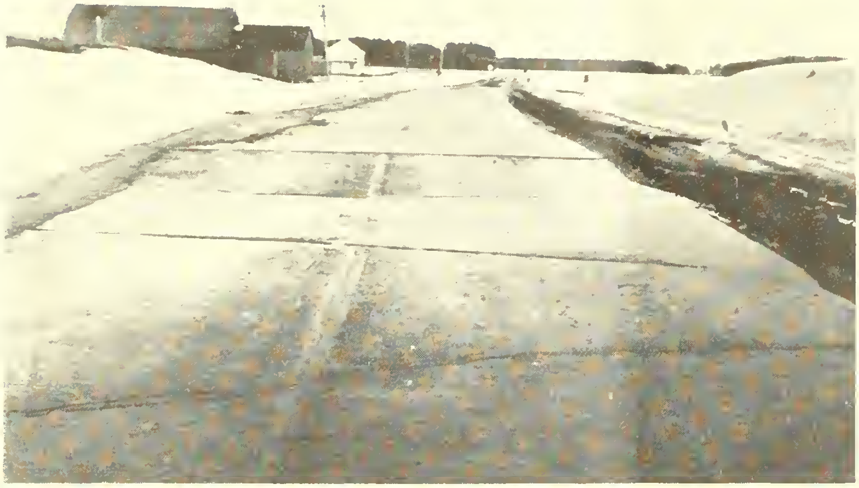
(*b*) Stratifications within the layer.

(*c*) Depressions in the profile of the layer boundaries which act as reservoirs for the collection of water in excessive amounts.

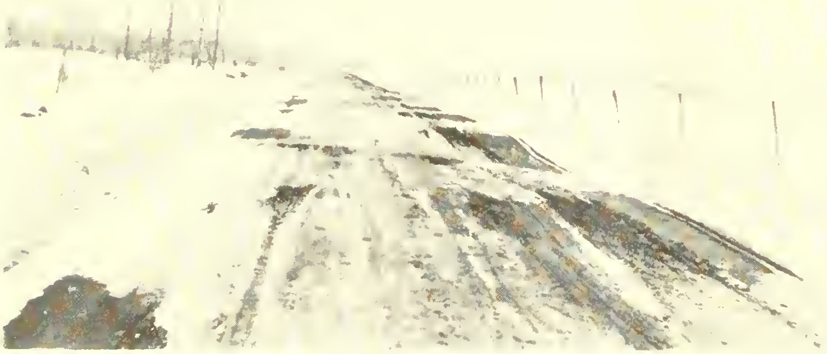
(*d*) Variation in the ground-water elevation due to the topography of the adjacent area.

Differential heaving of pavements productive of dangerous traffic hazards is generally due to variations in the soil profile. Figure 5 shows the different types of soil profiles in which the preventive measures described in this report were installed. Profiles *B*, *D*, *F*, *G*, *I*, *J*, and *O* were furnished by W. I. Watkins of the United States Bureau of Chemistry and Soils.

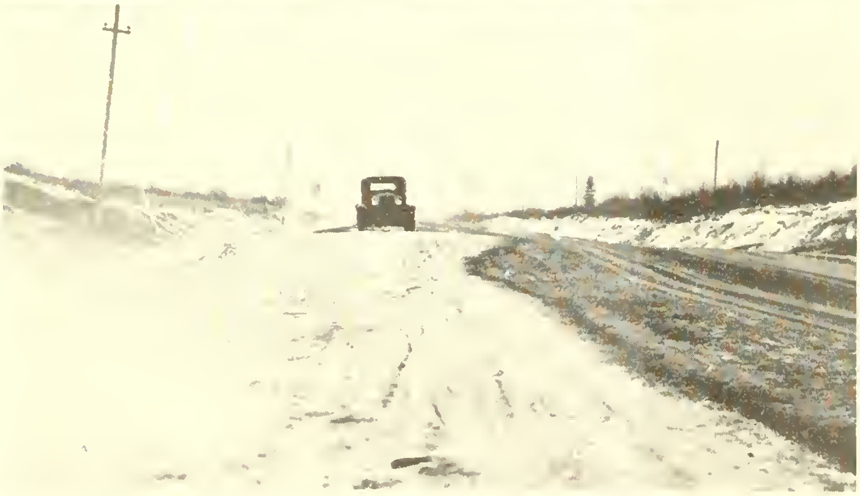
Figure 5–*A* illustrates the type of soil profile productive of the heaving shown in the top picture of figure 3. The pockets of silt and silty clay (group A–4 soil) varying in shape and depth occur within a deposit of porous sandy soils (group A–3 soil). The heaving in the silt pocket is excessive while that in the surrounding sandy soils is negligible. Considerable heave occurs



Abrupt and Hazardous Frost Heave of a Concrete Pavement.



A Series of Frost Heaves of a Gravel Surface.



Prominent Heave in a Gravel Surface.

FIGURE 3.—EXAMPLES OF TYPICAL HEAVING.

also in the pocket of silty clay. However, it is covered by an appreciable layer of sand (about 18 inches) which reduces the effect on the surface.

Figure 5–*B* shows a typical soil profile in the loessial area of Minnesota and Wisconsin. The frost heave is confined to that portion of the road resting on the unweathered or slightly weathered structureless silt. The weathered upper layers of the profile are granular in structure and apparently do not suffer detrimental frost heave.

According to the results of laboratory tests performed on representative samples of the various layers of the profile (fig. 5–*B*) the weathered silt loams and the structureless silt possess physical properties common to the group A–4 soils, while the underlying clay possesses the physical characteristics of the group A–6 soils.

The structureless loessial soil is a silt or silt loam containing a high percentage of very fine sand, has a high water-holding capacity, is unstable when wet, and

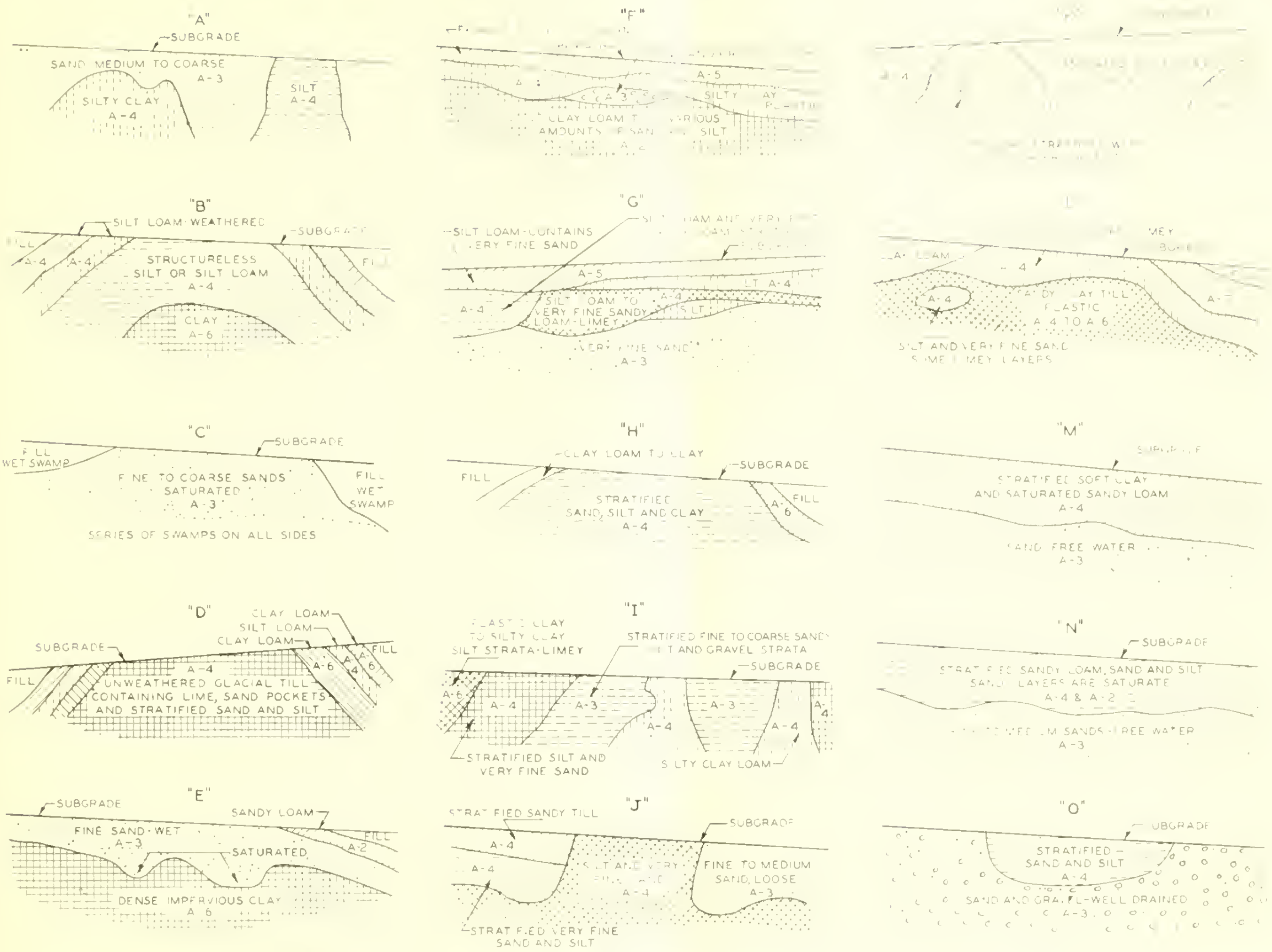


Figure 5.—Soil Profiles in Which Detrimental Frost Heave has been Observed.

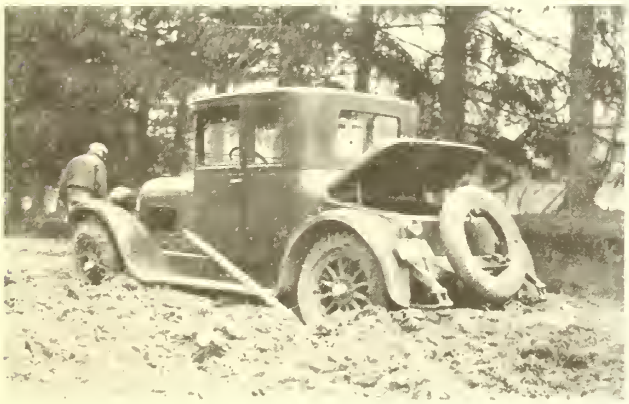


Figure 4.—Result of Thaw of a Frost-Heaved Gravel

possesses capillary properties in a high degree. Resting on a relatively impervious clay which retards percolation and forms a water table at its base, a condition is created favorable to strong functioning of the high capillary properties of the structureless silt layer. The clay may be at a considerable depth below the road surface and not necessarily in as close proximity to the surface as is indicated by figure 5 *B*. The bottom picture of figure 3 is characteristic of the type of heaving produced under the above conditions.

An example of detrimental frost heave in a sandy soil is illustrated in figure 5 *C*. The sand which varies from fine to coarse in texture and possesses physical properties indicative of the group A-3 soils is maintained in a saturated condition by a water table close to the surface. This is due largely to the topographic features of the adjoining terrain. The road cuts through small knobs or ridges, interspersed with bogs located both at higher and at lower elevations than the roadway. The middle picture of figure 3 is an example of the heaving produced in such a case.

A soil profile in extremely variable glacial materials is illustrated in figure 5 *D*. The relation between frost heave and the various layers of the soil profile is similar to that described for figure 5 *B*. In this case the heaving occurs in an unweathered glacial till containing lime, sand pockets, and stratified sand and silt. Water is transmitted to the roadway by the capillarity of the glacial till and also by the stratified sand and silt. Considerable amounts of water collect in the sand pockets.

The unweathered glacial till layer is essentially a group A-4 soil. However, it includes strata and small pockets of sand which possess the physical properties of the group A-3 soil. Such variations within a soil layer are especially productive of differential frost heaving.

Figure 5–*E* is an illustration of a soil profile in which heaving occurs as a result of depressions in the surface of an impervious clay. The dense clay restricts percolation of water and maintains the overlying sand in a wet condition while the sags in the surface of the clay layer act as reservoirs for the collection of water in excessive amounts. This condition is productive of the type of heaving shown in the top picture of figure 3 and attributed also to condition 5–*A*.

Figures 5–*F* and 5–*G* are examples of soil profiles in which the heaving results as shown in the bottom picture of figure 2. The profiles consist of a surface layer of more or less unstable A–5 soil underlain by silts and very fine sands (group A–4 soils) which occur in pockets and layers of varying thicknesses adjacent to water-carrying soil layers.

Figures 5–*H*, *I*, and *J* illustrate profiles which produce the greatest and most dangerous heaving. Stratified silt and very fine sand (group A–4 soil) invariably heave in such amounts as to rupture any type of superimposed road surface. Very dangerous differential heaving is produced when soil layers subject to detrimental heave in varying amounts are arranged in pockets as in figures 5–*I* and 5–*J*.

A different type of heaving condition is shown in figure 5–*K*. The laminated silty clay possesses physical characteristics of the group A–4 soils and performs in the same manner as the A–4 materials previously described. The group A–7 soil, however, is not generally subject to heaving. In this profile it includes very thin layers of silt which assist in keeping the clay very wet and soft.

The majority of the clay loam soils similar to those shown in figure 5–*L* are subject to detrimental frost heave only when wet and poorly drained but considerable heaving has been observed in fine sandy clay loam (group A–4 soils) containing appreciable amounts of disseminated lime. Where the road surface rests on lime-free clay loam of the group A–7 soils no serious damage has resulted.

The detrimental results of lime accumulations in a soil layer have been observed also in soil profiles where a limey clay loam of the group A–7 soils was found. Two adjacent clay loam soil layers in the same road cut were found to possess similar physical properties but the one containing lime heaved excessively while the layer free of lime did not heave enough to damage the road surface.

The soil profiles illustrated in figures 5–*M* and 5–*N* produce heaving similar to that of the stratified soils previously described and need no further discussion.

Differential heaving is certain where there is the extreme variation in soils as shown in figure 5–*O*. The pocket of soil subject to frost heaving is composed of strata of water-bearing sand and strata of silt which absorb water readily and resist all attempts at drainage. The sand and gravel (A–3 soil) surrounding this pocket is well drained and does not permit the accumulation of water, and no heaving occurs in the sand and gravel.

PREVENTIVE MEASURES DESCRIBED

Various methods used by different engineers in efforts to prevent frost heaving are shown in figure 6. Considering only the locations inspected in this survey, figure 6–*A* shows a method which has been used since 1921; figures 6–*B*, *C*, and *D* since 1928; figures 6–*E*, *F*, *G*, *H*, *I* and *J* since 1929; and figures 6–*K* to 6–*P* inclusive since about 1920.

The methods of excavating heaving soil and substituting a non-heaving material are illustrated in figures 6–*A* to 6–*I* inclusive.

Figure 6–J shows excavation of the heaving soil, treating the bottom of the excavation with bituminous material to cut off capillary action and replacing the excavated material.

Drainage channels to intercept and direct water away from the roadbed are shown in figures 6–*K* to 6–*P* inclusive.

Generally no more than 2 years are required for the surface condition to reflect the effectiveness of the preventive method used. This is especially true of methods which do not serve the requirements of the location. In such cases heaving has been observed during the first winter after installation. Therefore, the results of methods which have been in service since 1929 are considered fully as significant as those which have been in service since 1920.

RESULTS OF PREVENTIVE MEASURES DISCUSSED

The performance of these preventive measures employed in connection with different types of road surfaces and the associated local soil condition is described in table 1.

The narrow center trench types *A*, *B*, and *C*, serve to eliminate only that heaving which might occur directly over the area of the excavation. The soil on the sides heaves sufficiently to crack concrete and bituminous pavements. The damage to gravel surfaces caused by the frost uplift is ironed out by maintenance after the frost leaves the ground so that there is no visible aftermath of the winter condition. These methods reduce the amount of break-up during the spring thaws and allow passage of vehicles. Compared with the results where no precautions are taken (fig. 4) the benefits of this method are considerable.

Treatment for the full width of the traveled area as illustrated by type *D* has proven advantageous. There was no noticeable difference between the riding qualities of the surface laid over this type of treatment and adjacent sections where heaving had always been absent. The entire roadway remained smooth and firm during the spring thaw.

The V-type trench (type *E*, table 1) is very popular because it can be excavated with a blade grader, which materially reduces the cost of excavation. In most cases surfaces laid over subgrades so treated carry traffic in a satisfactory manner. However, the heaving at the sides of the trench 12 feet wide in soil profiles *D* and *J* and the general heaving in the trench 26 feet wide in soil profile *I* has, in some cases, developed to the point where driving is safe only at very low speeds. The surfacing in the heaved area is badly broken.

Measures *F*, *G*, *H*, and *I* have proved satisfactory and reliable methods of preventing detrimental frost heave of concrete pavements. Except under the extreme climatic conditions of the northern parts of Michigan and Wisconsin, heaving is negligible in treatments where the excavation and backfill is not less than 2 feet. Noticeable but uniform heave has been measured in treatments 1 foot deep.

The method of excavating the heaving material for the entire width of the roadway, treating the base of the excavation with a bituminous material and replacing the excavated material (type *J*, table 1) has not been quite as successful as the full width treatments described above. Gravel surfaces on bituminous treated soils

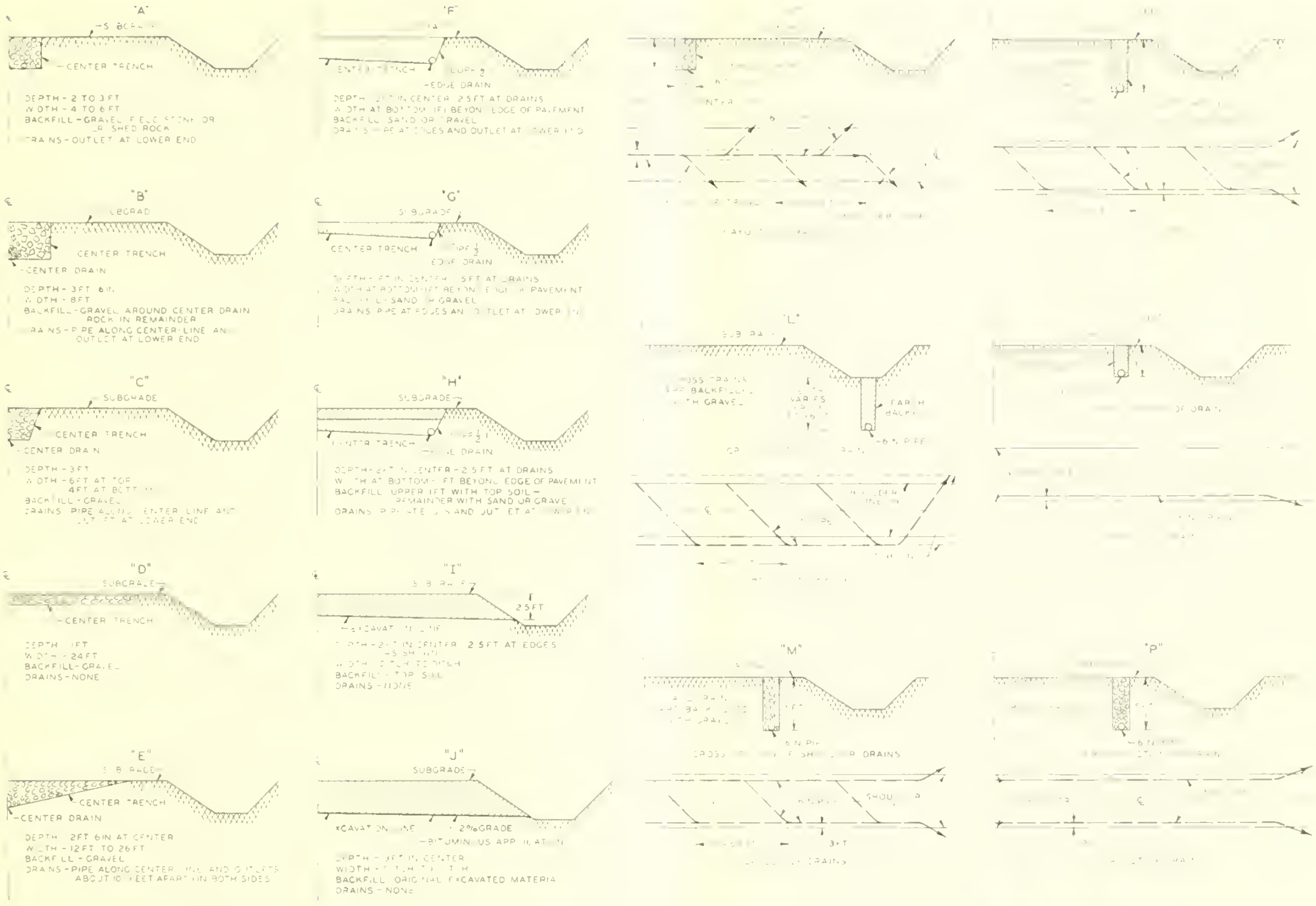


Figure 6.—Subgrade Designs used to Prevent Frost Heave.

have become uneven and rough and cut up during the spring thaw. The heaving of a concrete pavement is noticeable but fairly uniform. Cracking is more pronounced than in the locations where a selected back-fill material was substituted for the excavated frost heaving soil.

The various kinds of treatment should not end abruptly but should be tapered or feathered out. According to observations by Andrew Seifert, concrete pavements laid on gravel back-fill tapered from 10 to 25 feet cracked considerably and became noticeably rough. Fifty-foot tapers have been more satisfactory.

The result of type *K* subgrade treatment, is strikingly illustrated in figure 7 which shows how the gravel in the trench remains in place while the soil at the sides is forced up. The heaving at the sides of the narrow trenches previously described is similar in nature.

Table 1 shows that the drainage types *L* to *P*, inclusive, have been of practically no benefit in preventing heaving of soils. In most cases the drains have been placed at arbitrary depths of 3 to 6 feet without regard to the type of soil or the arrangement of the soil layers. Type *M*, when installed in water-bearing sandy soils (soil profiles *C* and *E*) in such a manner as to conform to the soil profile, served to intercept and carry away enough of the water to prevent detrimental heave. This same type, when used in the stratified silts, fine sands, and clays (soil profile *I*), was of no value whatever.

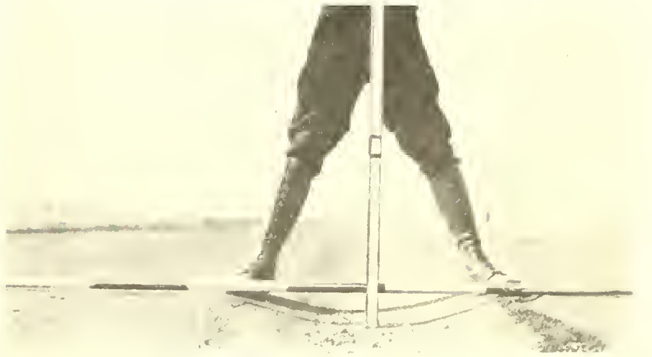


Figure 7.—Heaving at Sides of Narrow Trench Filled With Granular Material.

SOIL PROFILE MUST BE CONSIDERED IN DESIGN OF DRAINAGE SYSTEM

However convenient it would be to be able to establish definite and invariable spacing and depth requirements for drains, the hopelessness of thus standardizing drainage design becomes increasingly apparent as research in soils, especially for engineering purposes, progresses.

Failure to obtain the desired stability is definitely attributable in many instances to the attempt to apply arbitrary standards of spacing and depth in the placing of the drains without regard to prevailing conditions

Table 1.—*Results of frost heave preventive measures*

Type of treatment[1]	Type of surfacing	Soil profile[2]	Results	Remarks
A	Gravel	F, D	Heaved on sides during winter; surface softens during thaw. Carries moderate amount of traffic satisfactorily.	County roads; center trench 3 by 3 feet.
	Bituminous surface treatment	I, G	Heaved excessively on sides; no serious break-up during thaw.	Center trench 3 by 3 feet.
	Concrete	H	Heaved sufficiently to cause considerable cracking	Center trench 6 by 2 feet.
B	Gravel	B	Heaved a small amount on sides; no break-up	Center trench 8 by 3.5 feet.
C	do	J, L	Heaved on sides; slight softening and rutting during thaw. Carries traffic satisfactorily.	Center trench 3 feet deep, 6 feet at top, 4 feet at bottom.
	Concrete	L	Heaved on sides removing crown; considerable cracking.	Do.
D	Gravel	D	No heaving observed; smooth and firm; no break-up	Trench 24 by 1 foot.
E	Bituminous surface treatment	D, I, J	Heaved on sides in soil profiles D and J; surface broken but no rutting. Heaved badly in soil profile I; no rutting.	Treatment is 12 feet wide on soil profiles D and J and 26 feet wide on soil profile I, V-type trench.
F	Concrete	A to O, inclusive	Heave negligible, very small amount of cracking	Slightly wider than pavement.
G	do	L, M	No detrimental heaving; very small amount of cracking.	Do.
H	do	D, M	Heave negligible; very small amount of cracking	Do.
I	do	B, D, L, M	Heave negligible; small amount of cracking	From ditch to ditch.
J	Gravel	D	Uneven and rough; small amount of rutting; carries traffic satisfactorily.	Do.
	Concrete	B	Slight amount of heaving; fairly uniform; small amount of cracking.	Do.
K	Bituminous surface treatment	N	Heaved on sides of trenches leaving a narrow depression along the center line and over cross trenches; reduced surface break-up.	Rough riding and dangerous at times.
L	Gravel	D	Reduced break-up in most cases so that traffic could move across, although difficult; some sections impassable.	Very unsatisfactory in this soil condition.
	Concrete	D	Considerable cracking typical of frost heave	
M	Gravel	I	Impassable during thaw	This method apparently of no value in this soil.
	Concrete	C, E	Heave negligible; small amount of cracking	Depth of drains and location of cross drains varied to conform with soil profile.
N	Gravel	D	Soft and rutted in spots during thaw; carries traffic with difficulty.	
O	do	D	Impassable during thaw	No benefit derived from this method.
P	Bituminous surface treatment	D	Heaved breaking surfacing; carried traffic without breaking through.	
	Concrete	K	Heaved and cracked considerably	One section heaved to such an extent that the pavement had to be replaced.

[1] Refers to designs in fig. 6.

[2] Refers to soil profiles in fig. 5.

There is only one practical procedure and that is to place drains at such distances apart and at such depths as the interception and removal of offending moisture requires. And this, it can readily be seen, becomes a local problem, the solution of which depends upon such factors as the source of the water to be removed, the character of the soils comprising the different layers and the arrangement of the layers in the soil profile.

To further complicate the problem, some soils very readily give up their contained water and thus may be easily stabilized by drainage; other soils exercise a high affinity for moisture and are not apt to be stabilized by drainage. The only profiles found in this survey in which drainage can be reasonably certain to prevent frost heave are shown in figures 5–*C* and 5–*E*.

Figure 8–*A* shows how drains should be placed in order to prevent frost heave in soil profiles of the type illustrated in figure 5–*E*. Frost heave occurring in drainable soils due to a permanent high water table (fig. 5–*C*) may be eliminated by the system of drains shown in figure 8–*B*. It should be borne in mind that these methods are applicable only where the soil is more or less porous and does not possess capillarity in an appreciable amount.

CONCLUSIONS

The following conclusions may be drawn from the foregoing discussion:

1. Center trenches reduced the heave of adjacent gravel road surfacing during freezing and increased stability during thaws to some extent. As a result the damage to the road surfacing which did occur could be repaired by ordinary blading operations. These benefits are not sufficient to justify recommending narrow center trenches as a standard preventive measure. However, where scarcity of gravel makes full width treatment prohibitive, center drains 3 to 6 feet wide on the less traveled roads, and not less than 8 feet wide, or a width of one traffic lane, on the more important highways, may serve as temporary expedients prior to the construction of more permanent surfaces.

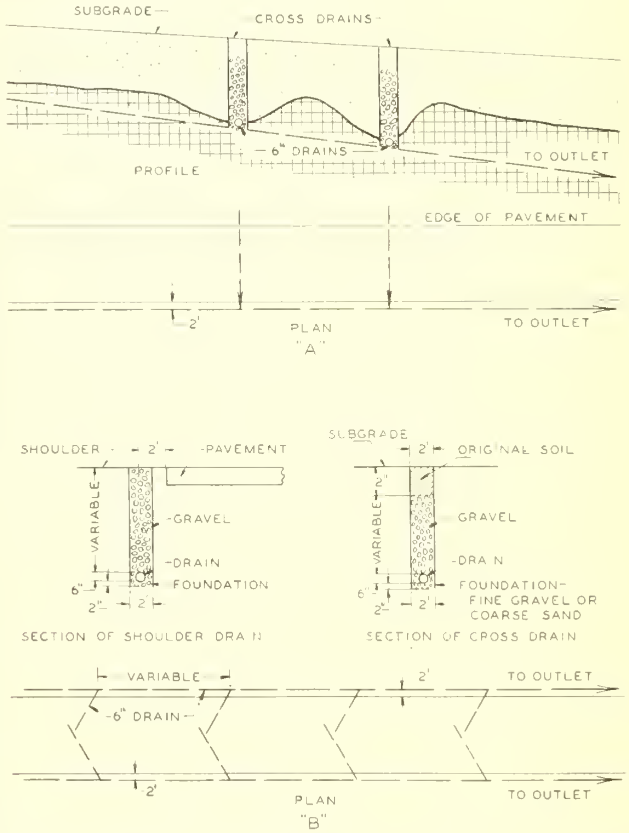


Figure 8.—Method of Preventing Frost Heave in Drainable Soils.

2. The measures adopted to prevent frost heaving of concrete road surfaces should be effective over an

(Continued on p. 25).

LABORATORY TESTS OF RESILIENT EXPANSION JOINT FILLERS

Reported by D. O. WOOLF, Associate Materials Engineer, and D. G. RUNNER, Assistant Materials Engineer, Division of Tests, United States Bureau of Public Roads

FOR MANY YEARS premolded fillers have been used in transverse expansion joints in concrete pavements to permit linear expansion of the concrete. The most widely used type has been a plastic compound consisting of bitumen and finely ground mineral matter between surfaces of felt paper. With linear expansion of the concrete, the bituminous filler is displaced and forced upward above the surface of the pavement. In some cases this extruded material is removed to preserve the smoothness of the pavement or is partly spread or worn away by traffic. In any event, subsequent contraction of the concrete results in the formation of an opening between the concrete and the joint filler since the bituminous filler, not being elastic, does not resume its original shape. Maintenance forces are expected to fill such openings with poured bituminous material so as to protect the subgrade from surface drainage. Due to the cost of this maintenance, efforts have been directed within the last few years toward the development of a resilient expansion joint which would absorb expansion of the concrete without appreciable extrusion of the filler and also expand upon subsequent contraction of the concrete, thus keeping the joint filled. A number of materials for filling expansion joints have been developed which manufacturers claim will produce these results.

TESTS COVERED ALL AVAILABLE TYPES OF JOINT FILLERS

In investigating resilient types of joint fillers, efforts were made to obtain samples representing the different materials used. Samples were obtained of sponge rubber, cane fiber, granulated cork, and compounds of asphalt and vulcanized rubber. A sample of the usual type of premolded asphaltic joint filler was also tested for comparative purposes. These fillers are described as follows:

Samples 1 and 2, brand A. Sponge-rubber fillers with nominal thicknesses of one half inch and 1 inch, respectively. The sponge rubber is placed between protective sheets of asphalt-treated felt. One edge of the filler is sealed with rubber to make a waterproof surface.

Sample 3, brand A. The usual type of preformed asphaltic filler with felt sides. Nominal thickness, 1 inch.

Samples 4 and 5, brand B. Sponge-rubber fillers with nominal thicknesses of one half inch and three quarter inch. The rubber appears to be of a much more open texture at the center than at either side of the filler. One edge of the one half inch filler and both edges of the three quarter inch filler are sealed with rubber. Both sides are protected with asphalt-coated felt.

Sample 6, brand C, is a sponge-rubber filler, one half inch thick. The rubber is of uniform texture, and is protected by felt sides. The edges are not sealed.

Sample 7, brand D, is a burlap-backed sponge-rubber filler with a nominal thickness of one half inch. The rubber is of uniform texture. The edges are not sealed.

Samples 8 and 9, brand E, are made of vegetable (cane) fiber, coated and impregnated with an asphaltic compound. No protective backing is used. The samples have nominal thicknesses of one half inch and 1 inch.

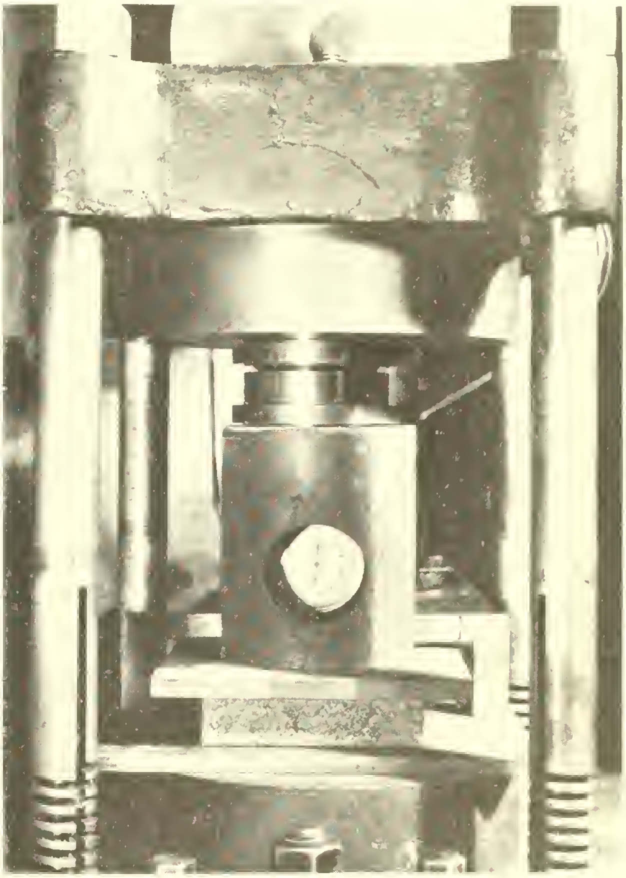


FIGURE 1.—APPARATUS FOR COMPRESSION TEST WITH EDGES FREE TO EXPAND.

Samples 10 and 11, brand F, are compounds of asphalt and fiber with particles of vulcanized rubber, some of which are three quarter inch in length. The surface of the joint is very irregular. The samples have nominal thicknesses of one half inch and 1 inch.

Sample 12, brand G, is composed of granulated cork bound with phenol formaldehyde resin. This material was submitted coated with an asphalt preparation and uncoated, but the manufacturers later advised that the coated filler was no longer used. Tests on the coated material had been started before this information was received and, since no difference was found between coated and uncoated specimens in trial determinations, the tests on coated specimens were continued. The material is of uniform texture, and has a nominal thickness of 1 inch.

Sample 13, brand H, is made of a compound asphalt and finely ground vulcanized rubber, and has a nominal thickness of one half inch.

TESTS DESIGNED TO REPRESENT SERVICE CONDITIONS

In selecting methods of testing to be used, an effort was made to duplicate as closely as possible the conditions to which joint fillers are subjected in actual service. These conditions include compression for varying lengths of time and weathering. The test methods adopted included measurements of the recovery of the filler after having been compressed a definite amount for various periods of time and, also, determinations of the effect of weathering, both natural and artificial. In addition, tests of the resiliency of the filler were made by determining the recovery following momentary compression of a definite amount.

Since the extended compression and weathering tests required considerable time, it was hoped that some correlation could be found between the results of the momentary compression tests and the extended tests. Another series of tests was made to determine the amount of extrusion of filler which might be expected in service. Some question arose regarding the amount of compression to which the filler should be subjected in these tests. Several manufacturers of fillers recommended compression to 50 percent of the original thickness, and this amount was used in all tests in which compression was applied.

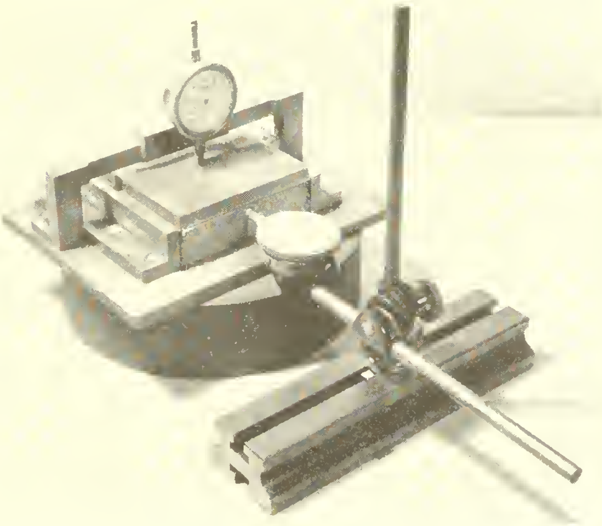


Figure 2.—Apparatus Used in Extrusion Test. Three Sides of the Specimen are Restrained.

The manufacturers of rubber fillers recommended that the felt sides be removed prior to tests for resiliency. It was decided, however, that the fillers should be tested in the same condition as when in service and all tests were made on the complete filler. This practice resulted in compressing the resilient portion of the filler to a somewhat greater extent than suggested by the manufacturers since the thickness of the felt sides was included in the measurement of the original thickness. In all cases "original thickness" refers to the thickness of sample as received in the laboratory.

In the test for resiliency, the specimen was placed between two steel plates and compressed to one half its original thickness in a universal testing machine at a free head speed of 0.05 inch per minute. The movement of the specimen was measured with an Ames dial reading to 0.001 inch and mounted on a bridge above the center of the specimen as shown in figure 1. Load was transmitted to the specimen through the steel cylinder which straddled the bridge and which had a port to permit observation of the Ames dial. When the specimen had been compressed to one half its original thickness the load was quickly released, and the recovery noted at 1 minute intervals for 5 minutes. At least 1 hour later the recovery was again determined, and the procedure repeated. After three compressions the specimen was permitted to recover for 24 hours, and a final reading of recovery made.

Extended compression tests were made to measure the resistance of specimens to fatigue. Specimens were compressed to one half their original thickness, clamped between steel plates, and held in compression for periods of from 7 days to 1 year. At the expiration of each period samples were removed from compression, and the recovery in 24 hours measured. The specimens compressed for 7 and 28 days were stored in the laboratory, but the 3-, 6-, 9-, and 12-month specimens were exposed to atmospheric conditions.

Tests for durability included exposure to the weather for periods up to 1 year, exposure to 5 cycles of freezing and thawing, and exposure to 140° F. dry heat for 7 days. Following each exposure, the specimens were tested for resiliency. These tests were made to determine if natural conditions have any appreciable effect on the specimens. Specimens exposed to the weather were clamped between steel plates with only enough compression to hold the plates snug. Specimens subjected to frost action in the laboratory were saturated with water and frozen in water. Frozen specimens were thawed in water at about 80° F. One cycle was completed each 24 hours. The heat tests were made in a small oven, the source of heat being one 100-watt electric light bulb.

In the extrusion tests, the specimen was compressed to one half its original thickness between steel plates with three sides of the specimen restrained. The apparatus used is shown in figure 2. This apparatus was placed in a universal testing machine and load applied to the plate covering the specimen as in the momentary compression tests. An Ames dial reading to 0.001 inch was mounted horizontally in front of the specimen and recorded any extrusion of the material.

At the start of this investigation it was the intention to use 6- by 6-inch specimens. The load required to compress some of the fillers necessitated the use of smaller specimens since only a 40,000-pound universal testing machine was available. In some cases in the recovery tests, specimens measuring 3 by 3 inches were used. In the extrusion tests two sizes of specimens, 4¼ by 4¼ inches, and 2½ by 2½ inches, were used. With the exception of samples 10 and 11, all materials were found to be fairly uniform in structure and behavior. The variations found in samples 10 and 11 are attributed to the large particles of rubber used in the composition.

SPONGE RUBBER AND CORK FILLERS SHOW HIGH RECOVERY AFTER MOMENTARY COMPRESSION

The results shown in the accompanying figures are the average, in each case of at least three individual tests, with the exception of the data for figures 10, 13, and 14. In these figures, each point represents the average of from 1 to 6 tests. Tabulated data showing the individual results are omitted in order to conserve space.

The results of the momentary compression tests are shown in figure 3. In these tests each sample was

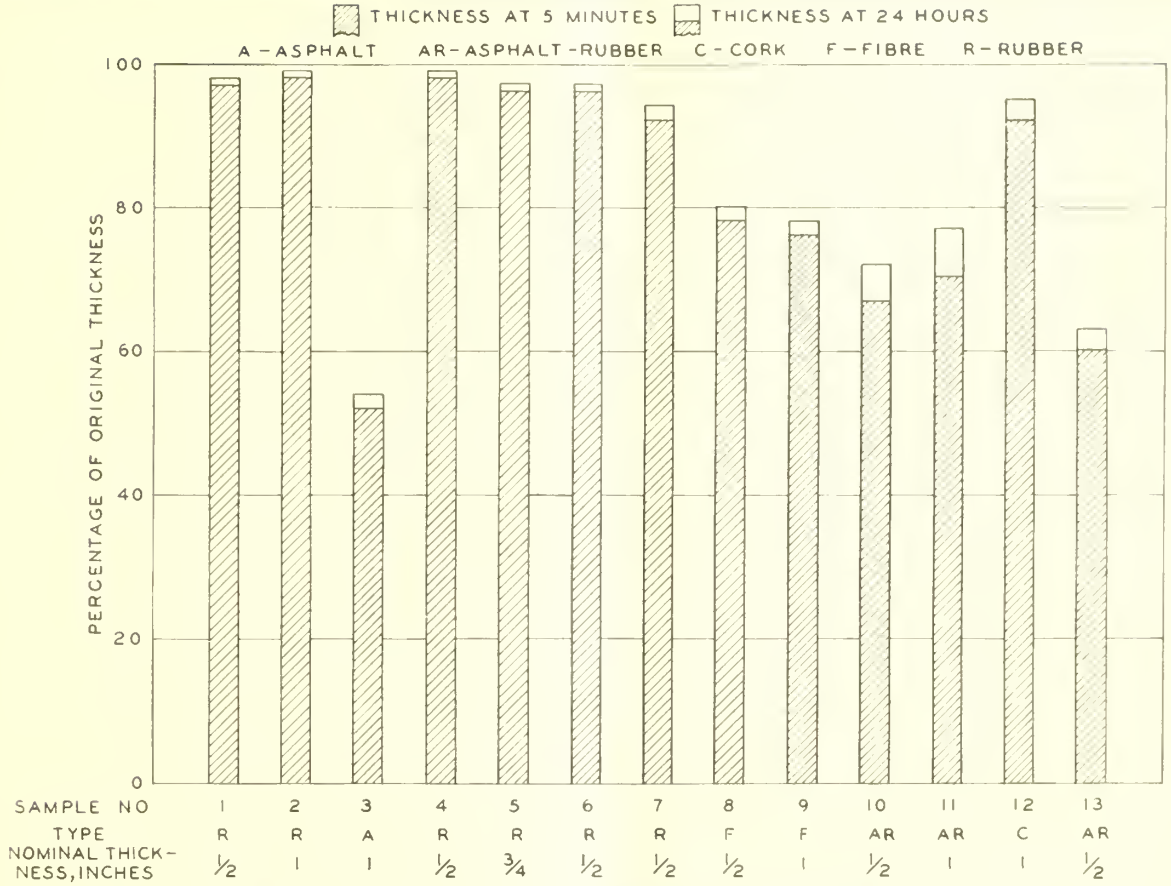


Figure 3.—Thickness of Samples After Three Applications of Momentary Compression and Recovery Periods as Indicated.

compressed three times to one half its original thickness with the load immediately released after each compression. Rest periods of 1 hour followed each of the first two compressions and one of 24 hours followed the third compression. The several sponge-rubber fillers and the cork fillers recovered to at least 94 percent of their original thickness. The fillers of cane fiber recovered at least 78 percent of the original thickness. The fillers composed of asphalt and rubber showed varying amounts of recovery ranging from 63 to 77 percent, the filler containing the finely ground rubber, no. 13, being the least efficient. The plastic asphaltic filler showed the least recovery of any specimen, as was expected.

Average curves showing the rate of recovery for 24 hours after release of pressure are given in figure 4. In most cases practically all of the recovery was obtained immediately upon release of pressure, and in only one case, that of the asphalt-rubber samples, was there any material increase in recovery between 5 minutes and 24 hours. It appears that accurate classification can be made with a recovery time of only 5 minutes.

Figure 5 shows the unit loads required to compress the different specimens to one half their original thickness. In several cases the load for the second and third compression was lower than for the one before it. This is accounted for by the relatively large set which occurred on the first compression. Due to this set, the material was not compressed to as great an extent on the second or third loading as on the first, and a smaller load was required. In some cases some change in the physical characteristics of the material occurred in the first compression, and a larger load was required thereafter to compress the material. This is illustrated by samples 1 and 5. The cork filler was apparently affected but little by the compression, since the loads required were practically constant for all three compressions.

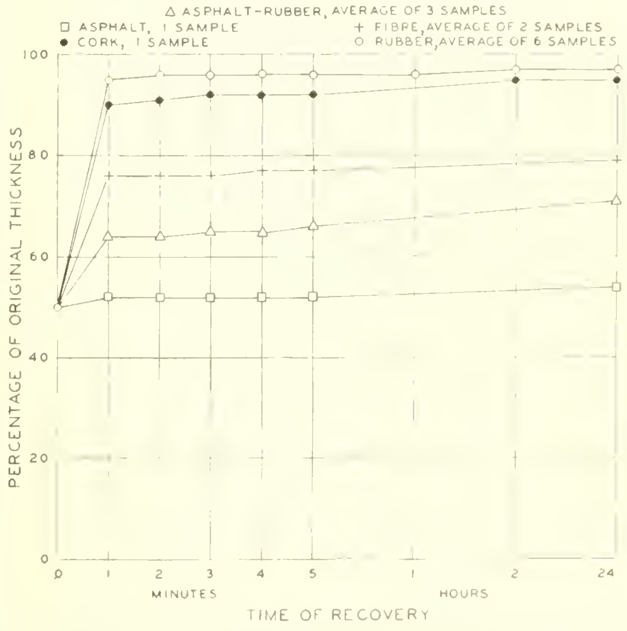


Figure 4.—Typical Time-Recovery Curves After Compression to 50 Percent of Original Thickness.

The sponge-rubber samples, nos. 1 to 7 but excluding 3, showed considerable differences in the load required

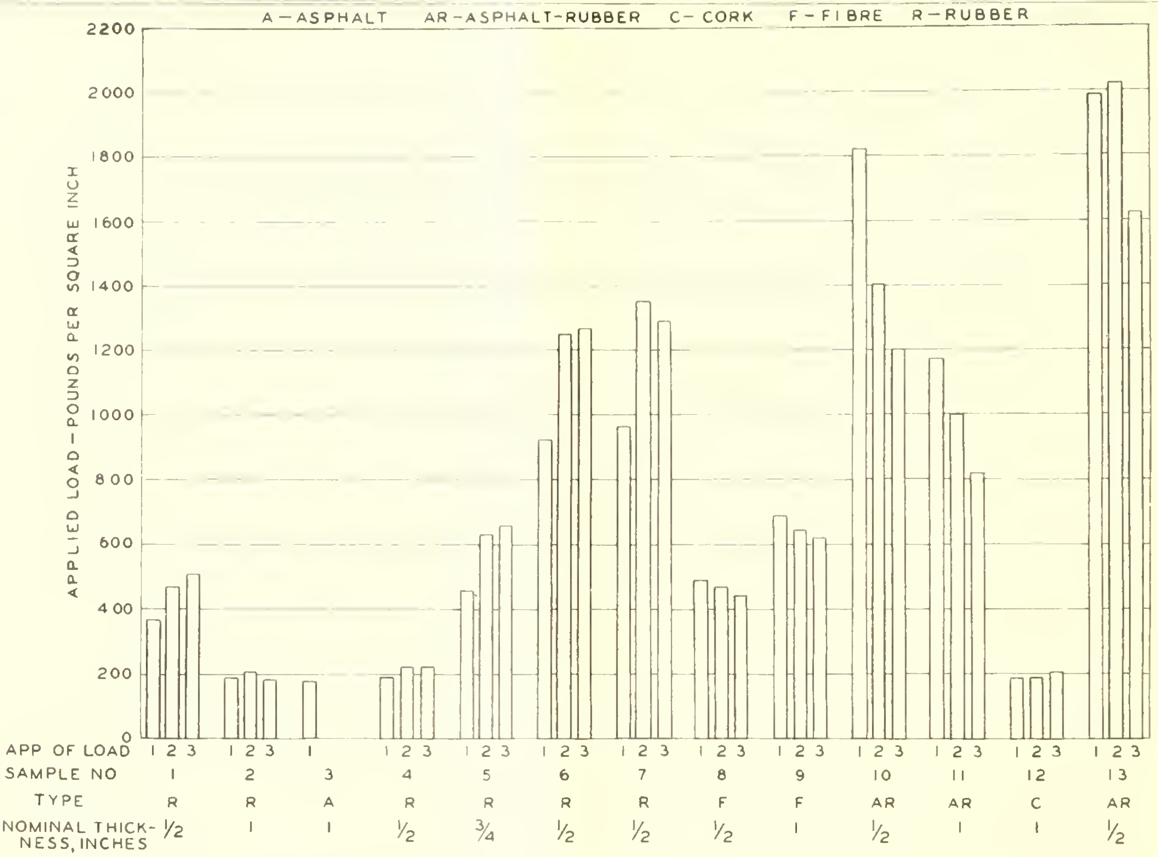


Figure 5.—Load Required to Deform Specimen to One Half its Original Thickness at Each of Three Applications of Load. No Restraint at Edges.

to compress them. Sample 1 required about twice the load required for sample 2, although both were made by the same manufacturer. Sample 1 was only one half as thick as sample 2 and, since the felt sides were not removed from the specimens, the rubber in sample 1 was compressed to a greater extent. It was expected that a greater load would be required. On the other hand, in the cases of samples 4 and 5, the thicker material required the greater load. Samples 6 and 7, which were both approximately one half inch thick, required relatively high loads to compress them to half of their original thickness.

The load required to compress joint fillers is of interest since it is an indication of the compressive stress in the concrete pavement when the joint filler is deformed. Other things being equal, the filler requiring the least load for compression might reasonably be considered the most desirable since the concrete would be stressed the least.

A specification for resilient joint filler suggested by a State highway department requires the determination of the resiliency after 5 compressions to one half of the original thickness with 1-hour rest periods after each compression. Samples of sponge-rubber, cork, and fiber filler were tested under the proposed method and the results compared with those obtained in the three-cycle test previously discussed. Figure 6 shows that comparatively little change was found after the first application of load. It is apparent that a measure of the resiliency may be obtained from the first few cycles of compression and recovery. The five-cycle test involving a testing period at least 2 hours longer than that required by the three-cycle test does not seem to be necessary.

DIFFERENT FILLERS VARY GREATLY IN AMOUNT OF EXTRUDED MATERIAL

The capacity of the testing machine available for these tests limited the size of the sample. A number of the specifications proposed by the manufacturers of filler materials recommended the use of a 4- by 5-inch test sample for the extrusion test. It was found necessary to use smaller samples and two sizes, 4¼ and 2½ inches square, were used. Tests were made on the samples of sponge rubber and cork filler using both sizes of specimen to determine if the size had any effect on the amount of extrusion. All specimens were compressed to one half the original thickness with restraint on three edges. No appreciable difference in amount of extrusion was found between the two sizes of specimen. It was found, however, that the extrusion of the sponge-rubber filler varied directly with the thickness of the material.

The results of the extrusion tests in figure 7 show the asphaltic and asphalt-rubber fillers to have the greatest extrusion. The sponge-rubber fillers showed extrusions of from one tenth to one quarter of an inch. The cork and fiber fillers had practically no extrusion. The cork, fiber, and most of the sponge-rubber fillers had no measurable permanent extrusion, the extruded material returning to its original position upon release of pressure. Samples 6 and 7 showed some permanent extrusion but this did not exceed 0.1 inch. The asphaltic and asphalt-rubber fillers had practically no recovery of the extruded material. Figure 8 shows a sample of asphaltic filler after the test. The extrusion on the left was permitted by a slight movement of the upper plate during the test.

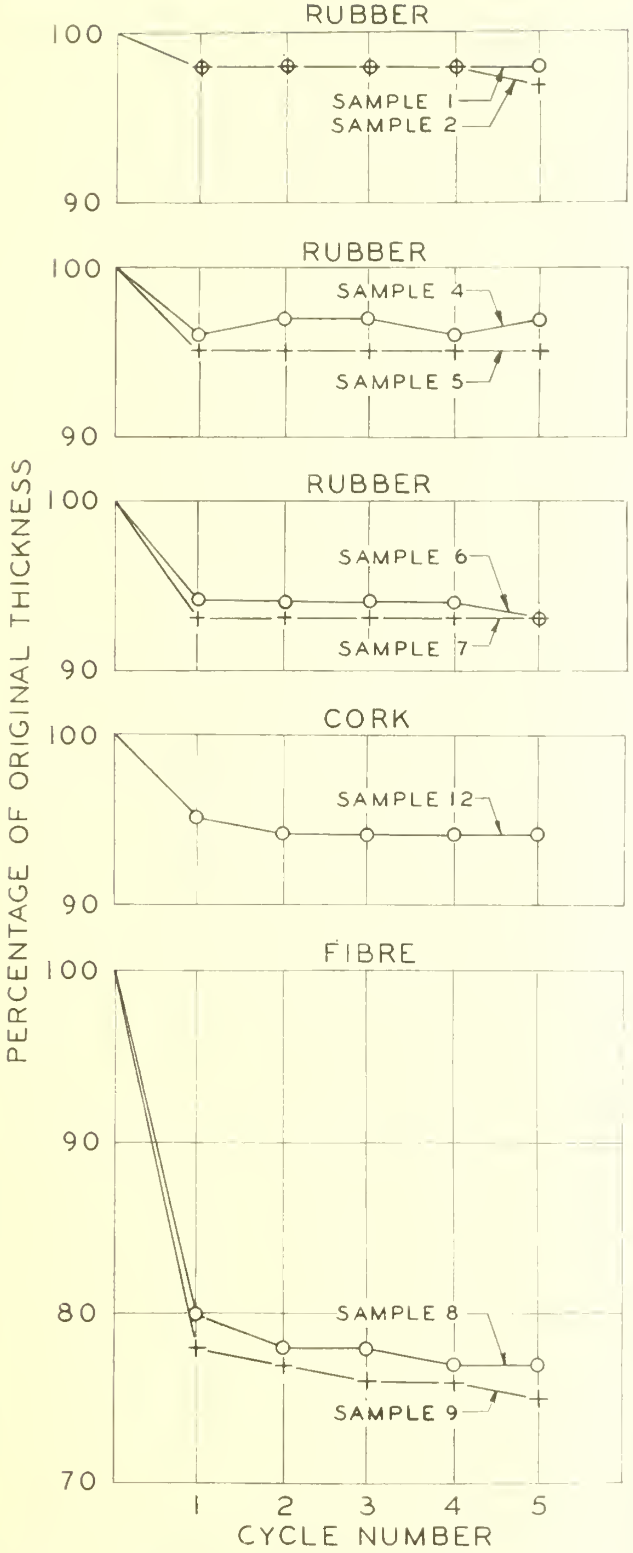


FIGURE 6.—THICKNESS AT 5 MINUTES AFTER EACH OF FIVE APPLICATIONS OF MOMENTARY COMPRESSION TO ONE HALF THE ORIGINAL THICKNESS. NO RESTRAINT OF EDGES.

In most cases the load required to produce compression to one half the original thickness was but little greater with three edges restrained than with all edges free. The asphalt-rubber samples and samples 6 and 7, of sponge rubber, however, required a considerably greater load with 3 edges restrained. Recovery of specimens after the two tests was approximately the same, as shown by figure 9.

SAMPLES EXPOSED TO NATURAL AND ARTIFICIAL WEATHERING

Tests to determine the effect of weathering were made by placing specimens between steel plates and exposing them to the weather. Sample 13 was not tested because it was received too late to obtain extended exposure without delaying the report. The cork joint, sample 12, was also received late and was exposed only 6 months. Samples were exposed to the weather for periods of 3, 6, 9, and 12 months and then subjected to three applications of momentary compression to one half of their original thickness at hourly intervals and after a 24-hour recovery period the thickness was measured. The average results are shown in figure 10. The sponge-rubber and fiber fillers apparently were not affected by the year's exposure to weathering. The cork filler showed no deleterious effect of weathering at an age of 6 months.

Considerable variation in the test results was found for the samples of asphalt-rubber filler. These samples, numbers 10 and 11, contained large pieces of vulcanized rubber. Some variation from sample to sample would probably be expected with small samples and it is believed that this variation accounts for the erratic results obtained. Considering the entire series of tests on the asphalt-rubber filler it may be said that there is no evidence of the effect of weathering.

A record of the temperatures to which the test specimens were exposed was obtained from a maximum and minimum thermometer placed beside the specimen racks. Figure 11 shows rather high maximum temperatures for the greater portion of the year. The test specimens were placed on the roof of a building near the wall of an adjoining building, where they were protected from the prevailing wind but exposed to the direct sunshine. The weather was mild and in only 5 weeks did the temperature fall below freezing.

Since expansion joint fillers would be subjected to more severe weathering in certain portions of the country, samples of the materials were exposed to both heat and frost action in artificial weathering tests. At the completion of each treatment, the samples affected were given three momentary compressions, and the recovery measured (24-hour recovery). Figure 12 shows that exposure to a temperature of 140° F. for a period of 7 days was found to have no appreciable effect on any of the samples tested.

In the freezing test, five cycles of freezing and thawing in water seriously affected some of the test specimens. One of the cane fiber specimens was completely separated into two parts, and others were partially split open. Failure, was of course, on a plane parallel to the surface of the material. Sponge-rubber fillers 4 and 5 were also affected by the frost action, the felt backing separated from the rubber and the rubber itself warped out of plane and, in some cases, expanded longitudinally. Reference to figure 12 shows, however, that the resilient properties of the damaged specimens had been affected only to a very slight extent.

Sustained compression tests were made as a measure of the enduring properties of the materials. Samples of each sponge-rubber filler were tested for periods of from 7 days to 1 year. Tests on the cork filler are now available for only 6 months since the material was received at a later date than the other samples. The great loss in resiliency resulting from the momentary compression of asphalt-rubber and cane-fiber fillers did not warrant further tests on these materials. However, tests on these types were made after sustained com-

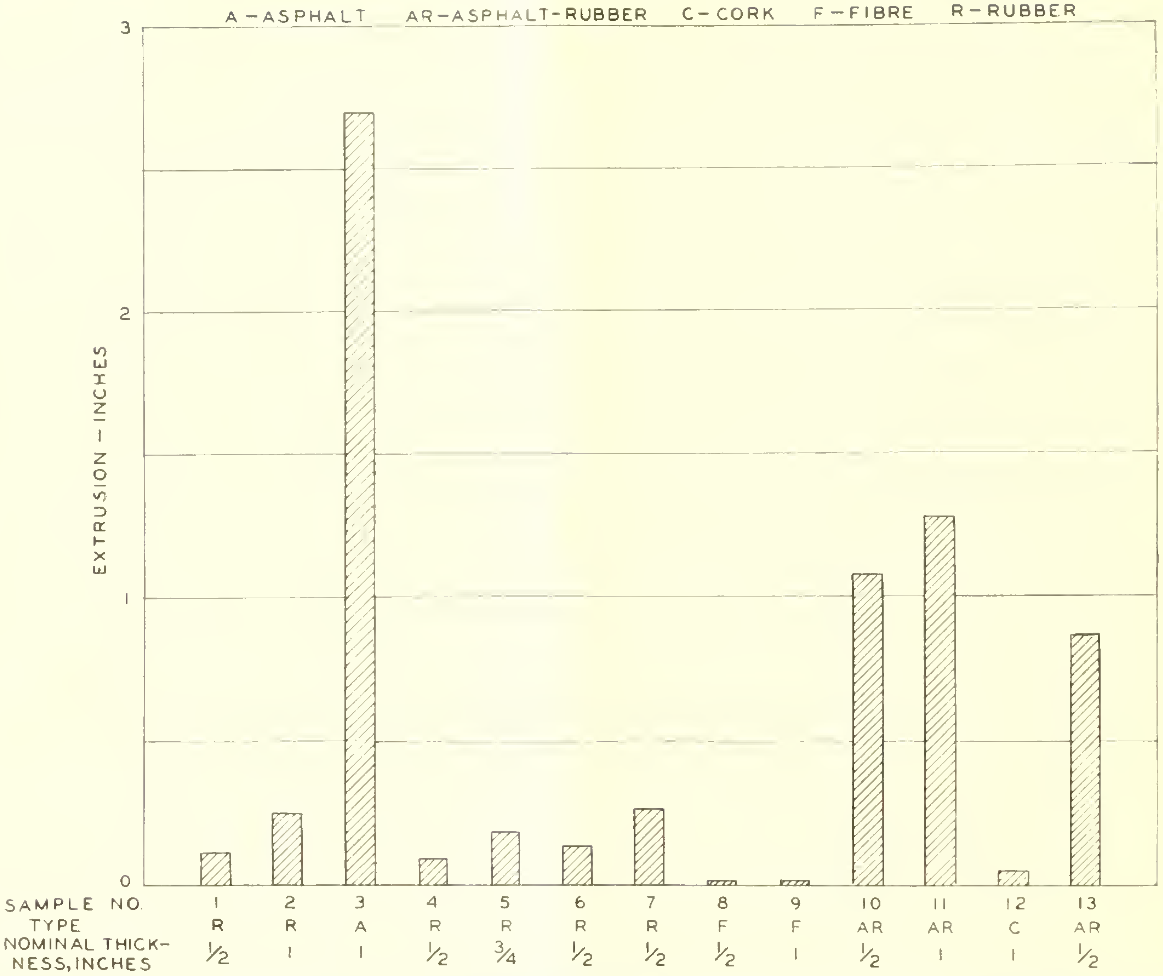


Figure 7.—Extrusion of Specimens When Compressed to One Half the Original Thickness and While Restrained on Three Edges.

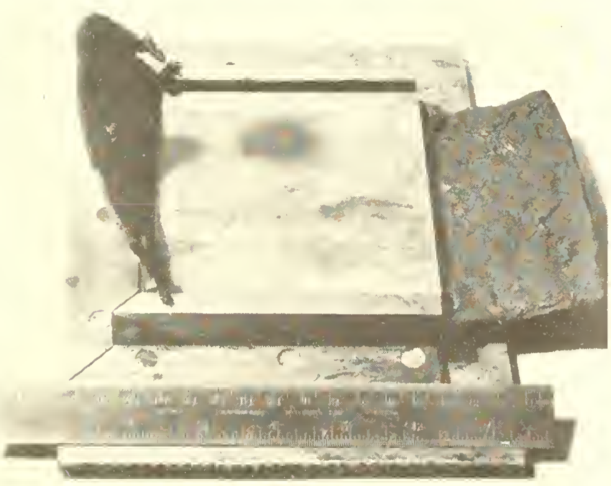


Figure 8.—Sample of Asphaltic Filler After Extrusion Test.

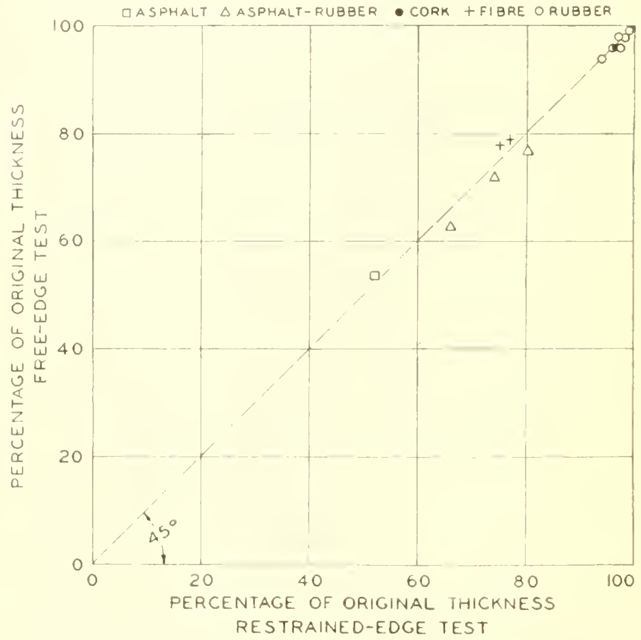


Figure 9.—Relation Between Recovery of Materials After the Free-Edge and the Restrained-Edge Tests.

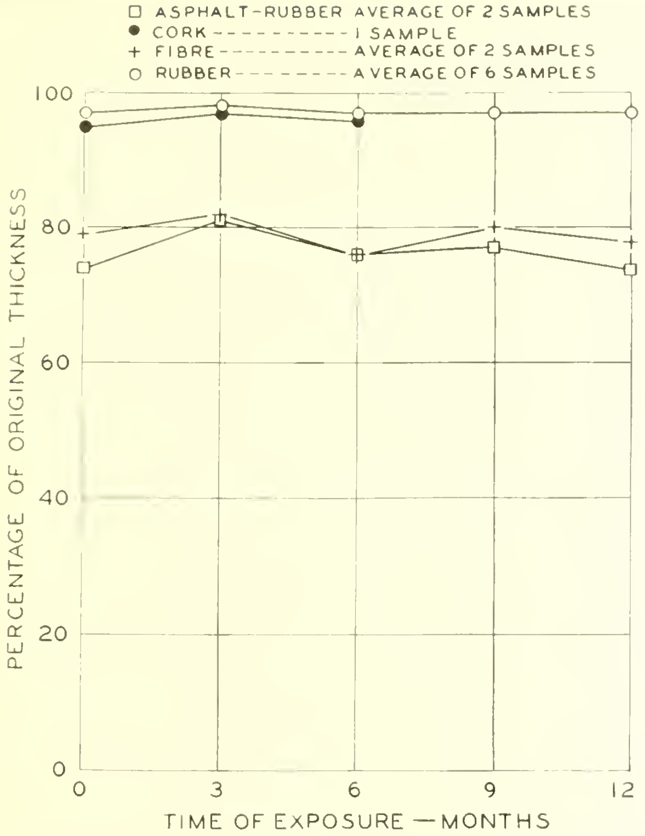


FIGURE 10.—EFFECT OF WEATHERING ON RECOVERY OF SPECIMENS. SAMPLES WERE EXPOSED FOR VARIOUS PERIODS, THEN COMPRESSED MOMENTARILY TO ONE HALF THE ORIGINAL THICKNESS THREE TIMES AT INTERVALS OF 1 HOUR AND RECOVERY MEASURED AFTER A 24-HOUR REST PERIOD.

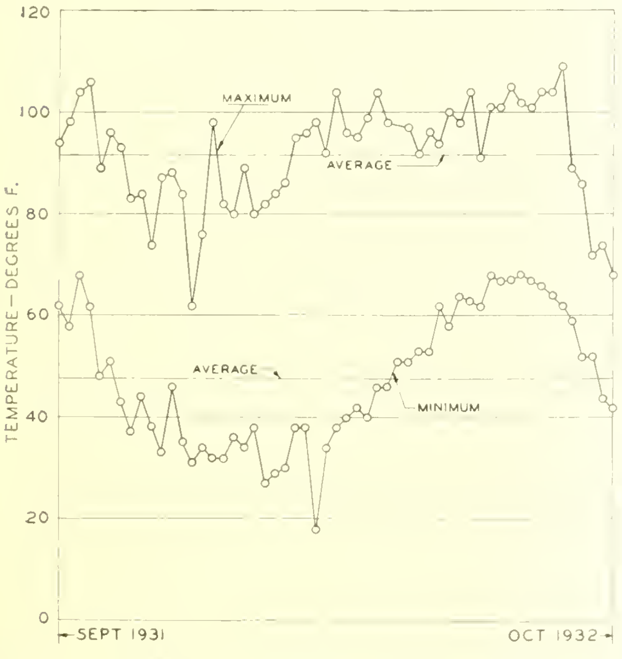


FIGURE 11.—TEMPERATURE RECORD DURING EXPOSURE TEST PERIOD.

pression for 7 days and 3 and 6 months. Asphalt-rubber filler no. 13 was not tested due to the lateness of receipt and the small amount of material submitted.

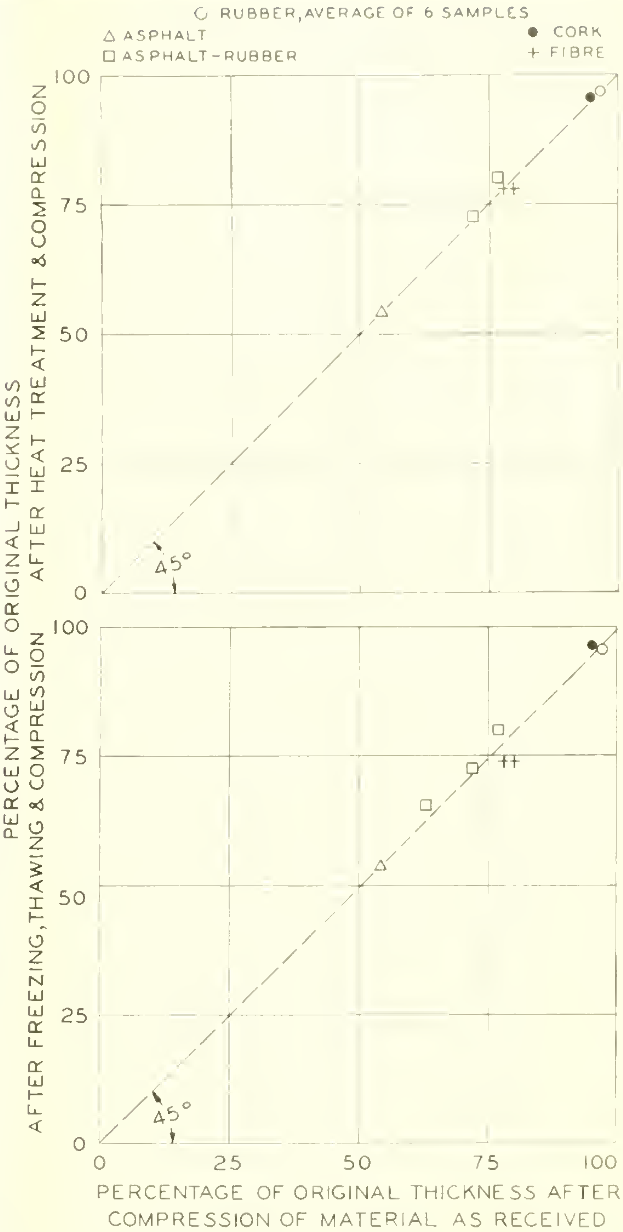


FIGURE 12.—RECOVERY AFTER COMPRESSION OF UNWEATHERED SPECIMENS COMPARED WITH RECOVERY AFTER COMPRESSION OF SAMPLES SUBJECTED TO ARTIFICIAL WEATHERING.

ALL SAMPLES SHOW PROGRESSIVE LOSS IN RESILIENCY WITH SUSTAINED COMPRESSION

The recovery of specimens after sustained compression is shown in figures 13 and 14. Figure 13 shows average values for each type of material while the results for each sample of sponge-rubber filler are shown in figure 14. A recovery period of 24 hours was used in all cases. The cork filler showed a progressive loss in resiliency with increase in time of compression. After being compressed for 7 days, the cork filler recovered to 90 percent of its original thickness, but after 6 months compression a recovery to only 63 percent was found. The sponge-rubber filler showed on the average somewhat better recovery at 7 days, but at 6 months the recovery was practically the same as for the cork. After being under compression for 1 year, the sponge rubber in general had practically no recovery. Con-

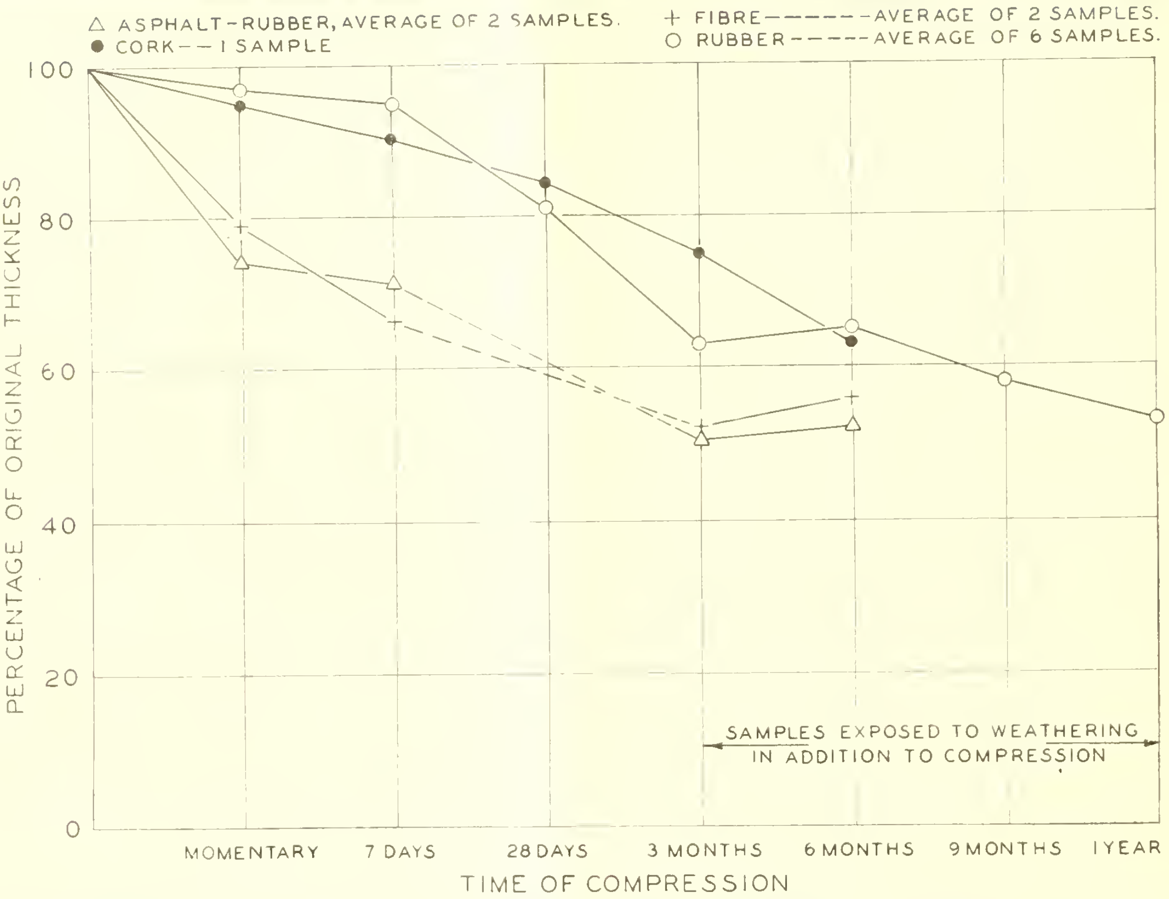


Figure 13.—Recovery of Specimens in 24 Hours After Various Times of Compression and Weathering.

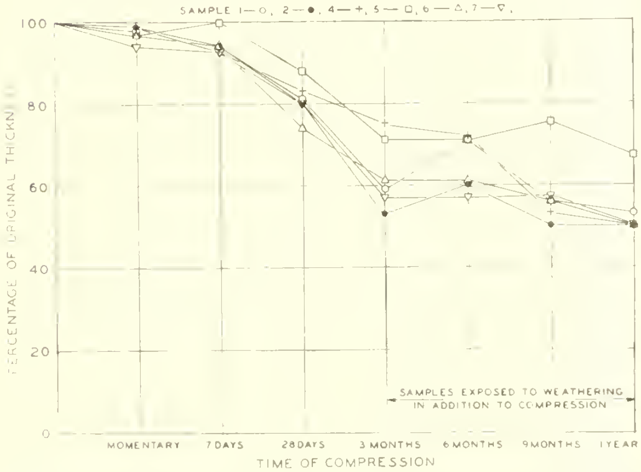


Figure 14.—Recovery of Individual Specimens of Sponge Rubber in 24 Hours After Various Times of Compression.

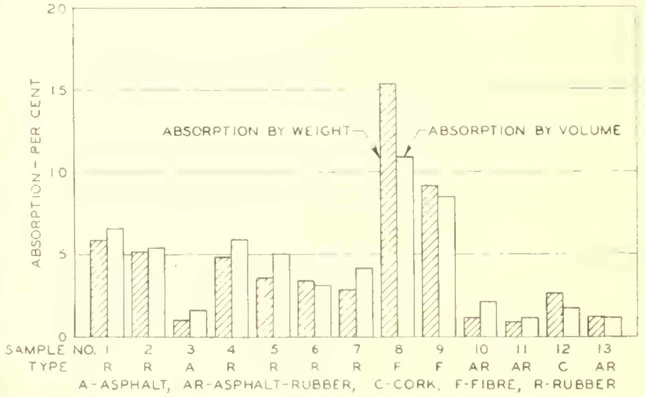


Figure 15.—Absorption of Specimens in 24 Hours.

sideration of the individual samples of sponge rubber indicates that one sample is somewhat superior to the others in resistance to fatigue. This sample, no. 5, showed a recovery to 67 percent after compression for 1 year. Sample 4, made by the same manufacturer, showed no recovery, and it is possible that the results for sample 5 may be somewhat in error. Four of the other samples showed no change in thickness upon release of pressure, and one recovered slightly to 53 percent of its original thickness. After compression for 28 days, all samples of sponge rubber showed recoveries of 74 percent of their original thicknesses or better. The fiber and asphalt-rubber fillers had relatively little recovery even after only 7 days compression, while at 3 and 6 months the recovery was practically negligible.

Absorption tests were made on all samples. Test specimens were weighed, immersed in water for 24 hours, wiped surface-dry and reweighed. The results given in figure 15 show the cane fiber filler to be the most absorptive and the asphaltic and asphalt-rubber fillers to be the least. The sponge-rubber fillers show absorptions varying from 2.8 percent to 5.8 percent by weight. The cork filler absorbed only 2.6 percent water by weight. In the case of the sponge-rubber and asphaltic samples the felt or burlap backing probably absorbed an appreciable amount of water.

While the tests reported in this investigation cannot be said to be complete, it is believed that sufficient data have been obtained to furnish a fairly accurate knowledge of the capabilities of the various materials studied. It must be said that the perfect expansion-joint filler is yet to be developed. None of the materials tested show all of the qualities desired in a filler. So far as resiliency is concerned, however, the majority of the materials tested are considerably superior to the plastic asphaltic fillers which have been used for many years.

Of the materials tested, the sponge-rubber and cork fillers appear to combine to the highest degree the features of resiliency, durability, and resistance to extrusion which are considered desirable in expansion joint fillers. The chief question regarding the sponge-rubber filler is the probable service life of the material. One year's exposure to the weather failed to cause any apparent change in the characteristics of the sponge rubber. However, no definite information is available beyond this period. No conclusions can therefore be drawn at this time regarding the relative durability of fillers of this type.

The cane or vegetable fiber filler possesses the best resistance to extrusion of any material included in this investigation. It is not very resilient and cannot be considered as efficient from this point of view as either sponge rubber or cork. Although the fiber joint is easily damaged by frost action, tests on frozen samples show no appreciable loss of resiliency. It is possible that after the material is installed frost action would have little deleterious effect on its performance.

Information obtained from various sources indicates that changes in length of as much as one quarter inch may be expected in a 40- to 50-foot concrete slab due to variations in temperature and moisture content. These tests indicate the desirability of using 1 inch of cork or sponge rubber filler for each 40- to 50-foot slab if it is desired to make allowance for the maximum expansion which may occur and at the same time have the joints tightly filled with desirable material.

The asphalt-rubber fillers appear to be the least desirable of the materials studied. These fillers show relatively little resiliency and have large amounts of extrusion. In these respects they are little better than the plastic asphaltic joint fillers.

CONCLUSIONS

The following conclusions appear to be warranted by the test results.

1. Considering the essential features of the resilient types of filler as determined by the tests described in this report, the different types studied may be rated as follows:

(*a*) Sponge rubber and cork
(*b*) Fiber
(*c*) Asphalt-rubber

2. The different samples of sponge-rubber filler exhibit a considerable range in physical characteristics, which warrants careful investigation of any particular material prior to use.

3. A compression test with 3 edges restrained is believed suitable for testing resilient expansion joint fillers. Measurements of the recovery, extrusion, and applied load can be made in a single test.

(Continued from p. 16)

area extending not less than 1 foot beyond the edge of the pavement and to a depth of not less than 2 feet. Excavation for the entire width of roadway and backfilling with selected material is preferable to the use of drains in excavated trenches.

3. The same preventive measures should be adopted for bituminous road surfaces as are employed for concrete road surfaces.

4. A porous granular material of the A–3 soil group should be substituted for excavated frost-heave soil. In locations where the cost of this type of material is excessive, topsoil may be used. The topsoil should be carefully selected from weathered soil layers and should be free from accumulations of lime.

5. Drains do not prevent frost heave in typical frost-heave soils such as the silts, silt loams, silty clays, and silty clay loams. According to the results of tests, most of these soils possess the physical properties of the group A–4 soils.

6. Frost heave caused by blocked drains or a high water table in porous A–3 soils may be prevented by the installation of drains. A thorough investigation of the soil conditions at each location should be made and the drainage system designed accordingly.

7. Frost heaving in profiles *C* and *E* (fig. 5) may be prevented by drainage. In order to eliminate detrimental frost action under the conditions represented by the remainder of the profiles, the frost-heaving soils should be excavated (or grade line raised) and selected material placed beneath the surfacing. The type of treatment should be governed by the permanence of the surfacing and the traffic requirements.

8. Information furnished by soil surveys, made prior to construction, should be utilized in fixing highway grades in such a manner as to correct the deficiencies of the natural soil profiles, with artificially constructed soil profiles. This practice will result in greater economy than the correction of defects in the subgrade after the grading and surfacing have been completed.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF FEBRUARY 28, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 4.185.067					$ 4.989.020.89	$ 2,755.265.47	$ 2.233.755.42	33.5	276.3	$ 235.186.30	28.0	$ 1,194.615.23
Arizona	3.804.731	$ 303.587.42	$ 303.587.42		21.6	3.299.720.65	2,835,025.45		34.3	231.1	68.539.45	.9	597.578.68
Arkansas	3.374.167	18.339.52	9.849.52	$ 8.490.00	.6	1.674.984.39	1.215.892.85	459.091.54	40.5	87.7	849.387.64	58.9	1.299.036.99
California	7.803.677	251,200.24	217.552.52		5.8	8.337.853.95	6.283.859.92		30.3	250.5	585,311.58	17.1	716.952.98
Colorado	3.437.265	728.229.51	728.229.51		53.4	1.478.907.19	1,468.326.84		33.1	59.1	282.296.35	3.7	958.412.30
Connecticut	1.404.213					1.230.901.72	1.055.122.78	175.778.94	6.7	26.6	346.048.17	6.4	3.042.05
Delaware	909.544	133.532.30	133.532.30		15.4	742.815.70	742,815.70		21.7	17.4			33.196.00
Florida	2.615.917	176.839.08	97.261.49	79.577.59	6.4	2,519.238.84	1.817,932.22	700.696.52	41.6	95.7	516.102.72	13.9	184.620.57
Georgia	5.045,592	130.924.84	130.924.84		5.5	2,146,766.41	2,146,766.41		36.9	129.0	745,464.53	56.9	2.022.436.22
Idaho	2.166.858	284.272.42	283,033.41		35.6	1.345.164.12	1.331.659.97		44.5	95.0	146.518.90	13.4	405.645.72
Illinois	4.431.348					1.038.589.29	1.038.589.29		18.8	24.1	567.012.04	8.0	2.825.746.67
Indiana	4.717.786					1,974.416.80	1.974.416.80		32.6	67.5	1.159.878.89	32.2	1.583.490.31
Iowa	5.027.830	704.773.93	704.400.00		30.0	4,153.957.36	3.848.330.00		29.7	223.2	358.250.00	15.7	116.850.00
Kansas	5.044.802	340.082.76	340.082.76		67.7	3.724.965.95	3.632.252.56		38.3	299.4	1.046.189.45	31.9	26,277.23
Kentucky	3.608.332	145.472.40	145,472.40		12.0	1.815.380.73	1.815.380.73		35.9	136.7	1.094.106.25	85.2	553.372.62
Louisiana	2,914.295	38.528.74	38.528.74		1.0	2.088,854.29	1.582,203.29		20.8	39.7	700,076.70	27.7	593.486.27
Maine	1.617.560					1,161.321.30	1.125.754.35		36.7	35.5	242.775.60	8.5	249.030.05
Maryland	1.782.263					801.143.78	791,495.03		8.2	14.8			990.767.97
Massachusetts	1.101.716	153.936.88	83.952.64	69.984.24	4.2	1,160.630.24	844.970.60	315.659.64	17.9	32.9	64.430.41	.7	108,362.35
Michigan	5.094.491	63.000.00	63.000.00		1.8	2.784,250.00	2.784.250.00		28.5	146.0	2.190.066.00	79.9	57.175.00
Minnesota	5.115.153	1.148.243.24	1.148.243.24		263.0	2.097,128.05	2.097.128.03		41.2	301.1	366.605.03	105.6	1.503.176.70
Mississippi	3.489.337					3.216.675.60	1.733.202.37	1.444.841.29	15.9	158.2	629.537.53	83.5	1.126.597.10
Missouri	6.090.153	318.173.69	219,506.32		20.1	4.063.325.13	3.723.740.33	50.048.60	37.1	130.4	871.040.85	32.4	1.275,865.50
Montana	4.463,849	221.309.34	221.309.34		34.0	3.744.987.76	3.472.108.88	192.878.88	37.5	268.7	640,792.56	40.9	129.638.22
Nebraska	3.914.481	381.081.97	255.420.54		144.8	3.915.261.27	3.036,632.94	108.538.00	41.9	180.1	460.859.94	53.4	161.567.58
Nevada	2.909,387	272.235.60	272.235.60		60.3	1,466.705.48	1.466.705.48		33.9	131.5	758.995.53	42.1	411.450.39
New Hampshire	725.739					573.516.95	567.831.95		29.8	9.8	68.469.25	1.1	89.437.80
New Jersey	3,065,137	12.742.75	12.742.75		.2	1.207.980.25	1.207.980.25		7.9	19.6	1.381.124.01	17.7	463.289.99
New Mexico	2,896.467	1.072,779.31	1.072.779.31		139.0	1.873.686.82	1.737.327.34	102.921.33	12.2	138.7			86.360.35
New York	10,182.526	117,100.00	117.100.00		3.8	9,631.250.00	8.658,575.00	315.000.00	25.0	205.7	1.248,590.00	28.0	158.261.00
North Carolina	4.761.147	567.604.75	321.021.30	246.583.45	44.0	1.839.373.64	1.533.949.37	305.424.27	23.5	196.7	1.306.568.04	240.0	1.599,608.29
North Dakota	2.902.224	506.686.40	506.682.89		258.9	873.842.71	873.842.71		15.3	228.3	1.193.654.38	380.1	328.044.02
Ohio	6.968.066	261,790.00	261.790.00		5.5	5.801.895.00	5.633.595.00		35.1	150.2	1.072.681.00	33.0	
Oklahoma	4.608.399	189.356.42	189.356.42		8.0	3.418,432.44	3.418.432.44		34.6	218.1	509.439.37	53.5	491.170.77
Oregon	3.053.448	350.457.26	322.563.76		40.4	2.352.972.89	2.204,545.69	58.505.67	28.3	111.2	412.750.38	29.9	113.588.17
Pennsylvania	5.757.978	12.791.10	12.791.10		.2	4.043.732.67	4.043,732.67		13.8	97.2	1.701,454.23	27.8	
Rhode Island	999.354	18.830.63	18.830.63		.6	969.153.21	969.153.21		26.7	20.0	10.468.37		901.79
South Carolina	2,729.583	4.168.89	4.168.89			1.826,973.64	1.824.244.02	2.729.62	35.4	169.9	282.842.64	22.5	618.327.45
South Dakota	3,005.739	871.013.41	865.096.92	5.916.49	144.9	1.101.467.48	1.069.443.19	32.024.29	11.2	177.2	498.160.33	59.3	573.038.56
Tennessee	4.246.309	131.887.64	72.591.00	59.296.64	5.1	2.691.692.56	2,174.971.82	516.720.74	29.6	98.7	1.431.281.52	59.1	567.464.66
Texas	12.122.012	651.879.59	494,793.34		157.2	7,967.735.36	7.063,543.71		29.1	639.2	1.933.798.20	201.6	2.629.876.75
Utah	2.374.205	869.670.21	869.670.21		101.6	1,058.173.84	1,057,778.94		31.6	80.9	219,567.89	10.6	227.187.96
Vermont	928.184	47.983.81	47.983.81		6.2	735.362.91	707.209.66		30.3	34.7	20.000.00	.5	152.990.53
Virginia	3.708.379	157.156.81	139.973.94	17.182.87	10.2	1,680.515.57	1.680,103.26	412.31	39.6	62.8	1.742.368.98	83.5	145.932.82
Washington	3.057.934	212.506.32	212.506.32		14.1	2.129.434.43	2.126.077.61	3.356.82	26.6	81.4	341.660.72	14.2	377,689.35
West Virginia	2.013,405	194.881.82	194.881.82		6.4	1.492,378.55	1.492.378.55		36.7	63.6	254.963.13	2.3	71.181.50
Wisconsin	4.862.441	298.477.25	288.174.42	1.190.00	15.7	2.581.337.60	2.559.238.07	21.500.00	37.2	101.7	664.009.68	63.1	1.351.018.83
Wyoming	2.250.663	680,509.21	593.153.00	60.000.00	118.6	1,565.534.20	1.411.700.00	18,000.00	21.8	325.8	29.682.61	11.5	216.127.39
District of Columbia													
Hawaii	1.683.956	25.988.65	12.994.33	12.994.32	.9	1,429.747.99	1.197.920.88	181.827.36	11.4	28.6	186.604.30	3.3	286.436.49
TOTALS	184.973.109	13.070,026.11	12.027.768.75	561,215.60	1.864.7	125.819.157.60	111.833.403.63	7.239.711.24	29.9	6.718.2	31.435.611.45	2.189.5	29.676.325.17

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF FEBRUARY 28, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 2.092,533	$ 29.479.63	$ 29,479.63		0.8	$ 299.579.46	$ 299.579.46		31.0	8.5	$ 297.352.30	9.7	$ 1.466.121.61
Arizona	781,794	6.427.92	6.427.92		.5	125.980.32	125.980.32		9.5	2.9	96.354.42	2.8	553,031.34
Arkansas	1,687.084					573.074.48	501.179.27	$ 71.895.21	28.3	16.1	373.068.64	10.9	812.836.09
California	3.901.839	107.821.54	96,674.88		3.1	2.184.283.71	1.922.291.90		20.7	27.9	836.261.89	8.9	1.046.610.33
Colorado	1.718.633	128.443.81	128,443.81		3.3	378,285.92	378.285.92		13.7	7.0	337.147.08	6.7	874,756.19
Connecticut	802.407	52,696.86	52.696.86		.5	430.230.83	430.230.83		30.2	6.9	255.987.28	2.3	63.492.03
Delaware	454.772	75.309.50	75,309.50		.9	149.600.00	149,600.00		5.3	1.0	50.710.00	.8	179.152.50
Florida	1,307.959					1.043.278.43	835.513.22	207.765.21	20.1	10.6	472.445.78	6.9	
Georgia	2.724,620	27.184.02	27,184.02		1.1	458.238.40	458.238.40		25.5	16.5	280.542.75	13.8	1,953.654.83
Idaho	1.197.829	22.257.32	22.049.37		1.7	330.125.37	326.160.97		16.2	5.5	82.133.43	4.1	767.485.23
Illinois	6.877.199	45.749.72	45,749.72		.5	2.905.279.75	2.905.279.75		11.8	30.9	3.254.737.89	33.9	671.431.64
Indiana	4.813.165	24.698.54	24.698.54		.4	18,031.73	18.031.73		22.2	.4	1.170.404.06	26.0	3.605.030.67
Iowa	2.815.585	244.716.01	242.350.00		8.6	776.439.00	732.415.00		14.9	15.4	681.750.00	19.0	1,159.070.00
Kansas	2.522.401	27.227.72	27.227.72		2.6	1,411,651.30	1.411.651.30		8.2	19.8	1,083.521.98	15.1	
Kentucky	2.029.687	13.307.85	13.307.85		.2	139.663.07	139.663.07		2.9	1.9	505.435.11	12.7	1.371.280.97
Louisiana	1.457,148	34.714.92	34.714.92		.2	323.725.57	323.725.57		59.9	6.4	167,260.18	7.6	931.447.33
Maine	909.878	79.296.57	79.296.57		1.6	350.433.41	350.433.41		33.4	8.5	312.148.18	4.7	167.999.84
Maryland	891.132					16.788.76	12.638.76		79.1	.6	—		878.493.24
Massachusetts	5.007.199	53.896.49	30,896.49	$ 23.000.00	1.4	3.150,737.00	3.136.637.00	14.100.00	14.3	12.7	250,293.28	1.1	1,589.372.23
Michigan	4.457.679	180.700.00	180.700.00		2.3	1.056.370.00	1,054.220.00		12.6	19.6	1.492.646.00	9.9	1,730.113.00
Minnesota	3.410.102	471.834.86	471.834.86		34.5	832.848.47	832.848.47		46.8	33.5	530.014.28	14.4	1,575.404.39
Mississippi	1.744.669					355,998.02	329.830,58	26.167.44	26.7	12.4	306.452.56	13.3	1.108.385.86
Missouri	3.045.077	4.587.13	3.305.88		.3	992.398.10	979.369.87		39.2	15.5	834,386.19	19.0	1,228.015.06
Montana	1.115.962	2.878.39	2,878.39		.1	374.033.85	374,033.85		25.1	10.4	151.076.18	9.1	587.973.58
Nebraska	1.957.240	29.267.12	28.577.83		3.6	1.013,524.35	1,013.524.35		32.6	16.5	834.675.77	14.1	80.462.05
Nevada	500.051	50.304.27	50,304.27		1.2								449.746.73
New Hampshire	706,640					353.502.08	353,502.08		12.4	7.5	352.837.92	9.0	
New Jersey	3,217.442	70.309.86	70.309.86		.8	1.782.488.30	1,782,488.30		24.2	12.5	820.908.72	7.7	543.735.12
New Mexico	1.448.234	10.526.42	10.526.42		1.0	490.082.67	490,082.67		22.4	9.2	471.729.58	11.6	475.895.33
New York	8,530.099	129.750.00	129.750.00		2.2	5.007.430.00	4.881.145.00		17.9	41.5	2.400.830.00	16.4	1.118.374.00
North Carolina	2.380.573	52.434.88	52.434.88		4.8	201.332.71	201.332.71		27.3	9.1	577.075.42	26.5	1.549.729.99
North Dakota	1.451.112	2.153.29	2,153.29		1.0	49,955.24	49,955.24		50.0	6.2	409,969.28	14.5	983,034.19
Ohio	4.645.378	66.830.00	59.355.00		2.0	1,399.084.43	1.309,793.43		21.0	16.0	2.485.759.00	36.0	790.470.57
Oklahoma	2.304.200	24.890,38	24,890.38		1.0	465.104.34	465.104.34		13.5	12.0	1.045.656.11	20.0	768.549.17
Oregon	1.526.724	23.731.40	23.731,40		.6	754.954.56	740.638.83	14.315.73	14.7	14.6	383.580.87	8.2	378.772.90
Pennsylvania	5.416.051	120.976.76	120.976.76		4.4	1,217.636.69	1.208,335.32		21.2	22.2	1.565.479.15	22.8	2.521.259.77
Rhode Island	499.677					155.048.79	155.048.79		3.2	2.4	106.304.22	1.8	238.323.99
South Carolina	1.364,791	24.919.48	24.919.48		1.7	307.304.30	306.899.29	405.01	16.3	15.3	138.038.95	6.3	894.933.28
South Dakota	1,502.870	75,816.40	75,816.40		4.7	158.605.22	158.605.22		13.9	5.9	209.590.01	8.7	1.058.858.37
Tennessee	2.123.155	19.992.06	19.992.06		1.2	566.629.72	566.629.72		19.2	7.3	380,995.19	6.7	1.155.538.03
Texas	6.061.006	124.266.13	104.642.19		9.2	1.710.575.57	1.580.519.44		25.1	58.4	1.676.566.00	25.5	2.699.278.37
Utah	771.826	369,762.28	369.685.28		8.8	187.426.30	186,467.30		34.3	4.9	58.995.40	2.0	156.678.02
Vermont	500.509	3.854.07	3.854.07		.6	298.777.26	297.549.64		21.8	8.2	153,245.15	3.6	45.860.14
Virginia	1.854.189	54.390.92	44.739.04	9.651.58	2.0	1,030.170.29	826.530.98		17.9	9.5	778.497.57	14.3	204.421.41
Washington	1.877.571	169.589.66	169.589.66		4.9	924.480.62	919.765.02		9.7	21.2	685.191.81	6.1	103.024.51
West Virginia	1.342.270	15.323.43	15.323.43		.4	362.465.66	338.119.92		17.2	5.6	526.204.30	8.5	462.622.35
Wisconsin	2.431.220	151.529.60	151.529.60		4.8	637.207.36	637.207.36		37.8	15.3	681.025.52	17.2	961.457.52
Wyoming	1.125.332	53.504.69	53.504.69		1.1	390.535.51	390.534.55		10.5	9.4	432.018.12	7.1	249,774.64
District of Columbia	959.235	295.510.62	295.510.62		2.4	570.729.00	570.729.00		15.4	1.7	92.921.15	.6	74.23
Hawaii													
TOTALS	114.268.748	3,572.862.52	3.496.843.54	32.651.58	129.0	38.712.425.92	37,458.647.15	334.648.60	20.2	623.3	31,090,224.67	547.9	42.223.032.64

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF FEBRUARY 28, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2,092.533				$ 93,344.43	$ 93,344.43	16.1	5.3	$ 83,707.07	7.6	$ 1.915.481.50	Alabama
Arizona	625.435				433,887.46	370.530.68	19.7	32.1			254,904.32	Arizona
Arkansas	1,687.084				331.611.51	331,611.51	8.4	21.6	211.195.30	38.9	1,144.277.19	Arkansas
California	3.901.838	$ 122,219.50	$ 85,059.65	1.7	1.714,358.42	1.443.414.25	17.3	112.1	886.688.28	28.7	1,486,675.82	California
Colorado	1.718.632	50,000.00	50,000.00	12.2	825.545.21	825,545.21	60.8	115.1	250.634.51	29.7	592.452.28	Colorado
Connecticut	659,120				664,915.58	659.120.00	2.1	14.5				Connecticut
Delaware	454.772								161.554.00	1.8	293,218.00	Delaware
Florida	1.307.958				1.203.489.02	1,203,489.02	30.8	68.3	28,436.47	.1	76,032.51	Florida
Georgia	2.320,973				359.481.66	359.481.66	12.5	27.3	338,604.91	19.7	1.622,886.43	Georgia
Idaho	1.121.562	67,404.64	63,302.38	7.0	810,860.83	778,839.50	44.3	117.6			279,420.12	Idaho
Illinois	6,262.223	78,787.21	78.787.21	19.3	1,824,519.04	1.824,519.04	14.7	154.0	1,974.498.84	109.6	2.384.417.91	Illinois
Indiana	501.892				189,508.90	189,508.90	16.9	42.4	168.415.02	11.6	143.968.08	Indiana
Iowa	2,212.245	85.897.35	83,000.00	27.3	625.320.05	595.300.00	32.8	53.3	387,300.00	52.9	1.146,645.00	Iowa
Kansas	2,522,401	11.865.47	11.865.47	3.8	1.107,780.33	1.107,780.33	9.7	99.0	1.387,307.18	61.4	15,448.02	Kansas
Kentucky	1,879.340	13.990.90	13.990.90	2.8	1,215.225.29	1,215.225.29	25.4	155.4	630,101.56	61.0	20.022,25	Kentucky
Louisiana	1.457.148				381.879.69	381,879.69	16.0	15.6	325.115.56	19.9	750.152.75	Louisiana
Maine	842.479	465,424.08	464,188.60	56.3	424,543.68	367.221.58	82.5	40.3	8.989.70	.2	2,079.12	Maine
Maryland	891.132				211.934.07	211.934.07	13.2	15.6	410,405.85	29.3	268,792.08	Maryland
Massachusetts	488.185				469,741.41	469.741.41	35.6	15.2			18.443.59	Massachusetts
Michigan	3.184.057	88.500.00	88,500.00	7.3	1.821.450.00	1.821.450.00	7.9	139.4	1.030.550.00	87.3	243.557.00	Michigan
Minnesota	2,131.314	46,377.25	46,377.25	34.7	1.388,608.93	1.308.177.93	34.2	199.9	298,501.02	34.4	478.257.80	Minnesota
Mississippi	1.744.669				435.000.00	435.000.00	43.2	54.6			1.309.669.00	Mississippi
Missouri	3.045.076	18,488.65	18.488.65	4.0	2.260,881.93	2.260.881.93	27.6	386.0	643.261.03	96.2	122,444.39	Missouri
Montana	1.859.937	79.392.69	79.392.69	16.0	704.516.02	704,516.02	5.4	68.0	827,038.34	111.3	248.989.95	Montana
Nebraska	1.957.240				1.757.064.92	1.755.202.60	28.2	250.3	202,037.40	33.6		Nebraska
Nevada	1.136.479				1,006.971.41	1.006,971.41	32.9	97.0			129.507.59	Nevada
New Hampshire	477,460				491.997.62	451.173.77	30.6	25.1	26.210.05	.5	76.18	New Hampshire
New Jersey	63,460				56,550.52	56,550.52	7.1	.5			6,909.48	New Jersey
New Mexico	1.448,234	9.000.00	9.000.00	4.0	1.071.950.00	1.071.950.00	38.9	681.2	63.900.00	73.0	303.384.00	New Mexico
New York	3.617.476	144.300.00	144,300.00	4.6	3.809.913.19	3,378,488.19	18.7	93.1	85.975.00	1.9	8.712.81	New York
North Carolina	2.380,573	145.298.61	145.298.61	18.4	1.086,726.77	1,086,726.77	35.6	98.4	17.611.55	.5	1.130,936.07	North Carolina
North Dakota	1.451,112								95.781.83	16.8	1.355.330.17	North Dakota
Ohio	3.871,148	133.950.00	133.950.00	44.6	2.548,530.00	2,433.394.90	22.0	228.4	1.083.260.00	34.8	220.543.10	Ohio
Oklahoma	2.304.199				152.421.47	152,421.47		10.9	611.975.75	100.8	1.539.801.78	Oklahoma
Oregon	1,526.724				775,189.12	757,716.98	14.9	27.2	653.650.00	62.3	115.357.02	Oregon
Pennsylvania	7.716.975	32,266.00	32.266.00	4.0	5.979,370.20	5.924.931.75	25.7	585.9	871,403.68	57.5	888,373.57	Pennsylvania
Rhode Island	499.677				72.438.03	72,438.03	2.8	7.0	209.313.33	19.1	217,925.64	Rhode Island
South Carolina	1.364.791				1.202.607.25	1.202.607.25	24.2	135.7			162.183.75	South Carolina
South Dakota	1.502.870	39.421.46	39.421.46	16.1	43.072.35	43,072.35	95.2	14.8	182,724.57	62.9	1.237.651.62	South Dakota
Tennessee	2.123.155				654,723.26	654,723.26	18.8	60.8	558.578.16	39.2	909,853.58	Tennessee
Texas	6.061.006	43.529.18	34,878.83	17.9	4.908.038.45	3.991,905.75	34.3	597.7	890,209.15	138.4	1.144.012.27	Texas
Utah	1,048.677	81.770.38	81.543.36	11.7	730.506.46	727.802.41	38.2	138.6	87.910.24	6.1	151.420.99	Utah
Vermont	438.880				327.772.79	309.469.49	21.3	28.8	110.432.98	7.0	18.977.53	Vermont
Virginia	1.854.189	28,000.00	28,000.00	20.5	1.407,746.40	1.339.583.75	36.7	178.3	366.594.40	14.8	120,010.85	Virginia
Washington	1.180,362	49.041.41	49,041.41	11.7	933,440.79	923.440.79	17.9	46.0	49.953.47	7.4	157.926.33	Washington
West Virginia	1.118.559				397.153.15	397.153.15	17.4	23.0	622.835.20	36.7	98,570.65	West Virginia
Wisconsin	2.431.220	26.056.01	26.056.01	.6	1.460,663.83	1,421.229.11	22.4	95.0	471.368.93	43.4	512,565.95	Wisconsin
Wyoming	1.125,332	32.972.04	31.300.00	4.1	705.187.44	690.965.00	39.1	104.9	259.453.20	30.3	143.613.80	Wyoming
District of Columbia	959,234	116.450.00	116.450.00	2.0	681.145.93	658.254.90		4.4	176,689.50	1.4	7.839.60	District of Columbia
Hawaii	187.106								180.042.06	4.9	7,063.94	Hawaii
TOTALS	94.758,143	2.010.402.83	1.954.458.48	352.6	51.759.584.81	49.466.686.05	25.7	5.485.6	17.930,215.09	1.595.4	25.406,783.38	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

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Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF FEBRUARY 28, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8,370,133	$ 29,479.63	$ 29.479.63		.8	$ 5.381,944.78	$ 3,148,189.36	$ 2.233.755.42	32.7	290.1	$ 616.245.67	45.3	$ 4,576,218.34
Arizona	5.211.960	310.015.34	310.015.34		22.1	3.859,588.43	3.331.536.45		31.7	266.1	164.893.87	3.7	1.405.514.34
Arkansas	6.748.335	18.339.52	9.849.52	$ 8.490.00	.6	2,579.670.38	2,048,683.63	530.986.75	32.4	125.4	1,433,651.58	108.7	3.256.150.27
California	15.607.354	481,241.28	399.287.05		10.6	12.236.496.08	9.649,566.07		26.4	390.5	2,308.261.75	54.7	3.250.239.13
Colorado	6,874.530	906,673.32	906,673.32		68.9	2.682.738.32	2.672.157.97		38.9	181.2	870.077.94	40.1	2.425.620.77
Connecticut	2,865.740	52,696.86	52,696.86		.5	2,326.048.13	2.144.473.61	175,778.94	10.0	48.0	602.035.45	8.7	66,534.08
Delaware	1.819.038	208,841.30	208,841.30		16.3	892.415.70	892.415.70		18.9	18.4	212.264.00	2.6	505.566.50
Florida	5.231.834	176,839.08	97,261.49	79.577.59	6.4	4.766,006.29	3.856.934.46	908,461.73	33.6	174.6	1.015.984.97	20.9	260,653.08
Georgia	10.091,185	158.108.86	158.108.86		6.6	2,964,486.47	2.964,486.47		32.2	172.8	1.364,612.19	90.4	5.603.977.48
Idaho	4,486.249	373.934.38	368,385.16		44.3	2.486.150.32	2,436.660.44		40.7	218.1	228.652.33	17.5	1,452.551.07
Illinois	17.570.770	124.536.93	124.536.93		19.8	5,768,388.08	5.768,388.08		14.0	209.0	5.796.248.77	151.5	5,881.596.22
Indiana	10.037.343	24,698.54	24,698.54		.4	2,181.957.43	2.181.957.43		31.2	110.3	2.498,697.97	69.8	5,332.489.06
Iowa	10,055,660	1,035.387.29	1.029.750.00		65.9	5.555.716.41	5.176.045.00		27.9	291.9	1.427.300.00	87.6	2.422,565.00
Kansas	10.089.604	379.175.95	379.175.95		74.1	6,244,397.58	6.151.684.19		26.2	418.2	3.517.018.61	108.4	41,725.25
Kentucky	7.517.359	172.771.15	172.771.15		15.0	3,170.269.09	3.170.269.09		30.4	294.0	2.229.642.92	158.9	1.944.675.84
Louisiana	5.828,591	73.243.66	73,243.66		1.2	2.794.459.55	2,287.808.55		25.5	61.7	1.192.452.44	55.2	2.275,086.35
Maine	3.369,917	544.720.65	543.485.17		57.9	1.936.298.39	1.843.409.34		45.2	84.3	563,913.48	13.4	419.109.01
Maryland	3.564.527					1,029,866.61	1.016,067.86		10.1	31.0	410,405.85	29.8	2.138.053.29
Massachusetts	6.597.100	207.833.37	114,849.13	92.984.24	5.6	4.781,108.65	4,451.349.01	329,759.64	17.2	60.8	314.723.69	1.8	1.716.178.17
Michigan	12.736.227	332,200.00	332,200.00		11.4	5.662,070.00	5.659.920.00		18.9	305.0	4.713.262.00	177.1	2,030,845.00
Minnesota	10.656.569	1.666,455.35	1,666,455.35		332.2	4.318.585.45	4.238.154.43		40.1	534.5	1.195.120.33	154.4	3.556.838.89
Mississippi	6.978.675					4,007,673.62	2.498,032.95	1.471,008.73	22.1	225.2	935.990.09	96.8	3.544,651.96
Missouri	12,180.306	341.249.47	241,300.85		24.4	7.316.605.16	6,963,992.13	50.048.60	34.3	531.9	2.348.688.07	147.6	2.626,324.95
Montana	7.439.748	303,580.42	303.580.42		50.1	4,823,537.63	4.550.658.75	192.878.88	31.5	347.1	1.618.907.08	161.3	966,601.75
Nebraska	7.828.961	410.349.09	283.998.37		148.4	6.685.850.54	5,805.359.89	108.533.00	36.1	446.9	1,497.573.11	101.1	242,029.63
Nevada	4,545,917	322.539.87	322.539.87		61.5	2.473.676.89	2.473.676.89		33.5	228.5	758,995.53	42.1	990.704.71
New Hampshire	1.909.839					1,419,316.65	1,372,807.80		25.6	42.4	447.517.22	10.6	89.513.98
New Jersey	6,346.039	83.052.61	83,052.61		1.0	3.047,019.07	3.047.019.07		17.4	32.6	2.202.032.73	25.4	1.013.934.59
New Mexico	5.792,935	1.092,305.73	1.092,305.73		144.0	3,435.719.49	3.299.360.01	102.921.33	22.4	829.1	535,629.58	84.6	865.639.68
New York	22.330.101	391,150.00	391.150.00		10.6	18,448.593.19	16.918.208.19	315.000.00	21.7	340.3	3.735.395.00	46.3	1.285.347.81
North Carolina	9.522.293	765,338.24	518.754.79	246.583.45	67.2	3.127.433.12	2.822,008.85	305.424.27	28.4	304.2	1.901.255.01	267.0	4.280.274.35
North Dakota	5.804,448	508.839.69	508,836.18		259.9	923.797.95	923.797.95		17.2	234.5	1.699,405.49	411.4	2.672.408.38
Ohio	15.484,592	462.570.00	455.095.00		52.1	9.749.509,43	9.376.783.33		29.7	394.6	4.641.700.00	103.8	1.011.013.67
Oklahoma	9.216,798	214.246.80	214.246.80		9.0	4.035,958.25	4.035.958.25		30.8	241.0	2,167,071.23	174.3	2.799.521.72
Oregon	6.106,896	374.188.66	346.295.16		41.0	3.883.116.57	3.702.901.50	72.821.40	22.8	153.0	1.449,981.25	100.4	607.718.09
Pennsylvania	18.891.004	166.033.86	166.033.86		8.6	11.240.739.56	11.176.999.74		20.9	705.3	4.138.337.06	108.1	3,409,633.34
Rhode Island	1,998.708	18.830.63	18,830.63		.6	1.196.640.03	1.196,640.03		22.2	29.4	326.085.92	20.9	457.151.42
South Carolina	5.459.165	29.088.37	29.088.37		1.7	3.336.885.19	3.333.750.56	3.134.63	29.6	320.9	420,831.59	28.8	1.675.444.48
South Dakota	6,011,479	986.251.27	980.334.78	5.916.49	165.7	1.303.145.05	1.271.120.76	32,024.29	14.4	197.9	890,474.91	130.9	2.869,548.55
Tennessee	8,492.619	151.879.70	92.583.06	59,296.64	6.3	3,913.045.54	3.396.324.80	516.720.74	25.8	166.8	2.370.854.87	105.0	2.632.856.27
Texas	24.244.024	819.674.90	634.314.36		184.3	14,586.349.38	12.635.968.90		30.3	1.295.3	4,500.573.35	365.5	6,473.167.39
Utah	4,194.708	1.321.202.87	1.320,898.85		122.1	1.976.106,60	1.972.048.65		34.3	224.4	366.473.53	18.7	535.286.97
Vermont	1.867.573	51.837.88	51.837.88		6.8	1.361.912.96	1.314.228.79		26.3	71.7	283,678.13	11.1	217.828.20
Virginia	7.416.757	239,547.73	212.712.98	26,834.75	32.7	4,118.432.26	3.846.217.99	412.31	33.9	250.6	2.887,460.95	112.6	470,365.08
Washington	6.115,867	431,137.39	431,137.39		30.7	3.987.355.84	3.969.283.42	3.356.82	20.7	148.6	1.076.806.00	27.7	638.640.19
West Virginia	4.474.234	210,205.25	210,205.25		6.8	2,251.997.36	2,227.651.62		30.3	92.2	1.404,002.63	47.5	632.374.50
Wisconsin	9.724.881	476,062.86	465.760.03	1.190.00	21.1	4.679.208.79	4,617.674.54	21.500.00	32.8	212.0	1.816.404.13	123.7	2.825.042.30
Wyoming	4.501.327	766.985.94	677.457.69	60.000.00	123.8	2,661.257.15	2.493.199.55	18.000.00	24.8	440.1	721.153.93	48.9	609.515.83
District of Columbia	1.918.469	411.960.62	411.960.62		4.4	1,251.874.93	1.228.983.90		16.1	6.1	269.610.65	2.0	7.913.83
Hawaii	1.871.062	25.988.65	12.994.33	12.994.32	.9	1.429.747.99	1.197.920.88	181.827.36	11.4	28.6	366.646.36	8.2	293,500.43
TOTALS	394.000.000	18.653.291.46	17.479.070.77	593.867.48	2,346.3	216.291.168.33	198,758.736.83	7.574.359.84	27.0	12.827.1	80,456,051.21	4.332.8	97.306.141.19

CLEMSON COLL

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 2 APRIL 1934

A BITUMINOUS CONCRETE MIXING PLANT

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 2 April 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

In This Issue

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

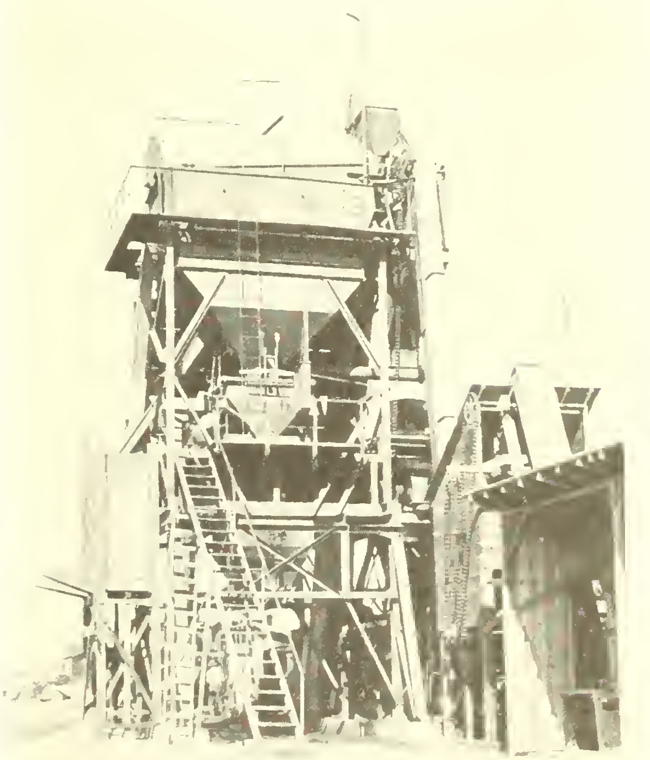
THE CONSTRUCTION OF HIGH-TYPE BITUMINOUS PAVEMENTS

BY THE DIVISION OF MANAGEMENT, U.S. BUREAU OF PUBLIC ROADS

Reported by C. F. ROGERS, Assistant Highway Engineer

IN 1926 the Bureau of Public Roads undertook a study of construction methods and costs on bituminous concrete highway projects. Twenty-three projects in 7 States with an aggregate length of 150 miles were selected for study. Each of the projects was designated by a job number which is used throughout this report. Details concerning the lengths of the projects, tons of surfacing for different courses and thickness of courses are given in table 1. The projects range in size from a minimum of 1,600 tons to a maximum of 49,000 tons.

To facilitate comparison, actual mileages have been adjusted to mileages of pavement 20 feet wide and of equivalent area. The tonnage per square yard and per mile for base and surface courses is shown for each project. The tonnage of material in base courses includes material used as a base in surface widening, full-width base sections on relocation, and the course ordinarily referred to as the leveling course and placed on the base. Surface courses include only top or wearing courses whether constructed on base of similar or dissimilar type. The average base and surface thickness has been derived for each project by calculations based on actual specific gravities developed in the various courses and actual weights of each course. Averaging the figures for all projects results in an average project with a 20-foot surface, 5.15 inches of bituminous mixture, 6.5 miles in length and containing 3,142 tons of material per mile. This average project required 20,426 tons of material, but recent projects have required approximately 54,000 tons in 12 miles and 65,000 tons in 14 miles.



A Modern, Large-Capacity Plant Showing Screens, Bins, Mixer, and Storage Box. Trucks Drive Straight Through in Loading.

Table 1.—*Length, thickness, and quantities involved in projects studied*

Job no.	Length of 20-foot pavement equivalent in area	Quantities required			Surface area	Quantities per square yard			Quantities per mile			Number of courses	Thickness		
		Base	Surface	Total		Base	Surface	Total	Base	Surface	Total		Base	Surface	Total
	Miles	*Tons*	*Tons*	*Tons*	*Square yards*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*		*Inches*	*Inches*	*Inches*
	8.28	16,294	9,458	25,752	97,104	0.168	0.097	0.265	1,968	1,142	3,110	3	3.25	1.79	5.04
2	9.09	18,877	9,951	28,831	106,653	.177	.093	.270	2,077	1,095	3,172	3	3.42	1.72	5.14
3	6.57	------	5,599	5,599	77,082		.073	.073	----	851	851	1	-	1.51	1.54
4	5.89	5,496	5,209	10,705	69,064	.080	.075	.155	933	881	1,817	2	1.55	1.12	2.97
5	13.91	17,134	21,392	38,526	163,501	.105	.131	.236	1,228	1,533	2,761	3	2.03	2.42	4.45
6	4.58	5,459	3,318	8,807	53,701	.103	.062	.165	1,192	731	1,923	2	1.99	1.17	3.16
7	4.40	6,967	5,951	12,918	51,672	.135	.115	.250	1,580	1,319	2,929	2	3.08	2.32	5.40
8	1.55	1,307	3,153	4,460	18,210	.072	.173	.215	813	2,034	2,877	2	1.65	3.52	5.17
9	6.59	15,353	7,733	23,086	77,332	.199	.100	.299	2,326	1,172	3,198	3	3.85	1.85	5.70
10	3.45	3,191	2,953	6,141	40,121	.079	.073	.152	925	856	1,781	2	1.53	1.38	2.91
11	6.26	8,931	9,724	18,658	73,157	.122	.132	.254	1,425	1,551	2,976	2	2.79	2.69	5.48
12	6.19	11,198	7,642	18,810	72,667	.154	.105	.259	1,809	1,234	3,043	3	2.98	1.99	4.97
13	2.75	--------	2,393	2,393	32,292	--	.074	.074	-	870	870	1	-	1.50	1.50
14	1.41	------	1,638	1,638	16,595		.099	.099		1,161	1,161	1	--	1.99	1.99
15	2.29	3,916	2,252	6,198	26,831	.117	.084	.231	1,723	983	2,706	2	3.36	1.69	5.05
16	7.27	15,316	10,180	25,496	85,333	.180	.119	.299	2,107	1,100	3,507	3	3.48	2.20	5.68
17	4.34	4,286	3,862	8,148	50,925	.081	.076	.160	987	890	1,877	2	1.77	1.50	3.27
18	9.85	26,776	13,327	40,103	115,519	.232	.115	.317	2,721	1,355	4,076	3	4.49	2.13	6.62
19	12.20	29,680	19,270	48,950	143,162	.207	.135	.312	2,433	1,579	4,012	3	4.00	2.50	6.50
20	4.49	9,144	8,410	17,554	52,617	.173	.160	.333	2,037	1,873	3,910	3	3.34	2.96	6.30
21	9.63	26,238	13,447	39,685	112,992	.232	.119	.351	2,725	1,396	4,121	3	4.49	2.20	6.69
22	8.62	21,593	12,163	33,756	101,151	.211	.120	.334	2,505	1,411	3,916	3	4.13	2.22	6.35
23	9.89	29,823	13,733	43,556	115,981	.257	.119	.376	3,019	1,390	4,109	3	4.97	2.20	7.17
Weighted average	6.50	12,044	8,382	20,426	76,271	.158	.110	.268	1,853	1,289	3,142		3.11	2.01	5.15

By far, the greater number of projects studied consisted of surfacing laid directly on old cement concrete pavements, although a few surfaces were placed on new subgrade or on new cement concrete base. In all cases, except one, the surfacing was placed between side forms of wood, steel, or concrete and finished to these forms. All of the single-course pavements were laid on cement concrete base of a lean mix, and a thickened-edge section with curbs for lateral support. In the case of the one project where side forms were not used the base was made 1 foot wider than the surface course.

The mixes used include those commonly referred to as sheet asphalt, fine aggregate bituminous (or asphaltic) concrete, coarse aggregate bituminous concrete, and modifications of certain patented types of pavement on which patents are no longer operative. In the study of rates of production and costs, only those items directly related to the actual pavement are included and such items as subgrading, form-setting, and production of materials are omitted.

The projects were all of such size as to justify construction with a single plant set-up. In most cases the plants were located near the center of the job but factors such as the location of satisfactory sidings, space rentals, and accessibility made it desirable to locate some plants at a distance from the center.

TYPICAL PROCEDURE IN BITUMINOUS CONCRETE CONSTRUCTION DESCRIBED

Figure 1 shows the plan and elevation of a typical bituminous concrete plant. Aggregates are usually delivered by rail to an adjacent siding. From 2 to 4 separated sizes are delivered. The aggregate is moved from the cars to stock piles from which the "cold bucket-elevator" is fed. At some plants the unloading is done by crane and at others the tracks of the siding are elevated permitting bottom-dumping of cars and gravity feed to bins or piles. Gravity feed from bins to the bucket elevator with the flow regulated by control gates is frequently used. Belt conveyors are also used, particularly for the sand. The different sizes of aggregate should be fed to the elevator in the proportions required for the mix as nearly as is possible.

The cold elevator hoists the material to the dryer for drying and heating. When this operation is completed the material is discharged by gravity to the hot pit beneath. At some plants, a blower and dust collector (see fig. 1) is used to by-pass the fine, dry material to prevent clogging the dryer. The fine material is wasted or deposited in the hot elevator pit with the larger heated aggregate.

An elevator raises the material from the hot pit to screens at the top of the plant where it is separated into the required sizes and then deposited in storage bins located over the weighing hopper. Where filler is used, it is generally conveyed from ground storage to a separate bin from which it may be fed by gravity or screw conveyor to the weighing box.

A boiler is used to furnish steam for heating materials and to operate the various power units. The boiler is usually heated by fuel oil which is stored in tanks and pumped to the boiler. Asphalt is drawn from cars and stored in an underground tank where it is heated by steam coils or tubes. The asphalt is pumped from this pit to the mixing platform on the main tower of the plant just above the pug mill.

A batch is proportioned by allowing each size of aggregate to flow into the weighing box in the proper amount as determined by weight. The aggregates are then dumped into the pug mill, which is in continuous operation, and the asphalt is admitted while the materials are being agitated. On completion of the mixing the batch is discharged through a steam-activated discharge gate to a storage box or directly to hauling equipment.

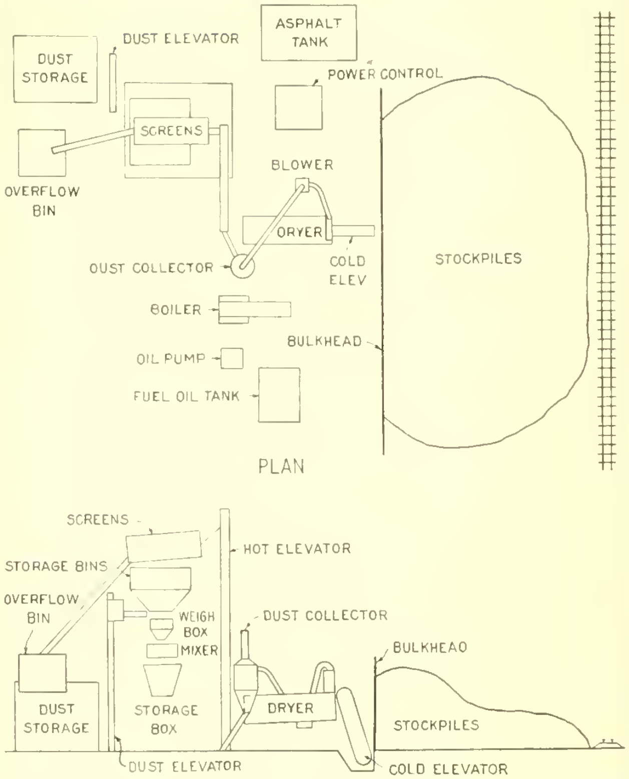


Figure 1.—Typical Arrangement of Mixing Plant.

The mixed material is hauled to the road and deposited directly on the surface or in spreader boxes. It is then either shoveled and raked into place or it is spread with the spreader boxes. Following the initial spreading, the final spreading and raking is often done by hand but recently, particularly in the west, the mechanical finishing machine has to a large extent replaced hand finishing.

Rolling is done with a variety of types of rollers. Both the macadam and tandem type are used and weights range from 3 to 15 tons.

PLANT MODIFICATIONS DESCRIBED

Many modifications from the plant arrangement which has been described were observed but the general methods remained unchanged. On some projects in the Middle Western States the various plant accessories were built around a mixing unit mounted on a railroad flat car. With such plants the economy of easy movement is largely offset by small capacity which is inherent in the design. At one large plant, an elevator fed hot material to screens and batcher on one tower and a second elevator raised the batches to a hopper supplying the mixer on another tower. This arrangement reduced the over-all height of the plant. At another plant of medium capacity the units were arranged horizontally on low towers with furnace, dryer, screen hopper, and mixer assembly, and power plant in the order named. Most of the plants studied had very desirable jacking and other devices for assembling units with speed and facility. The plant design which provides a balanced flow of materials through the several units with a minimum number of simple mechanical devices will also provide the greatest freedom from breakdown and delay.

TIME DISTRIBUTION AND DELAY STUDIED

Although the plants studied varied somewhat in their arrangement, the particular functions of the various units were comparable. On every project there was a limiting unit or bottle neck, past which the materials could flow only in definitely limited amount. The removal of this bottle neck at one unit would only transfer it to some other unit which would then fix the rate of production. The purpose of the time study has been to derive the limiting rate for each unit or part of the plant and gradually to synchronize the several units by adjustment of size and speed or improvement of control of moving parts.

Stop-watch studies covering thousands of hours were made of repetitive operations, such as loading, batching, and mixing. Analysis of these data resulted in detailed information concerning operating cycles and capacity of each unit. An accurate record was kept of the cause and amount of all delays. Delay or lost time was classed as "major" or "minor." Major delays are definite stops in excess of 15 minutes and may occur during working hours or as a prolonged shut-down. Minor delays occur only during working hours under full expense and are usually of greater relative cost than major delays. They may be only a few seconds in duration but may recur frequently in cyclical operation. Study of stop-watch records for typical hours of operation indicated the extent of each kind of delay and comparisons were made on a percentage basis. It has been assumed that such percentages reflect the time distribution during all of the working hours. The correctness of this assumption has been checked by comparison with records covering protracted periods and the error is found to be less than one tenth of 1 percent.

Job time or "available time" is based on the length of the average working day and the days of job duration with the exception of Sundays and holidays. The elimination of major delays from available time results in "working time" during which the full crew is always on the job. The subtraction of minor delays from working time results in "utilized time" during which the plant is operating at 100 percent efficiency. In conducting the study both major and minor delays were classified as to causes and also as to whether they were avoidable, partly remediable by good management, or unavoidable.

The results of such studies are shown in tables 2 and 3 and figure 2. The nature and extent of all major and minor delays observed in the time studies on each of the 23 jobs are shown in table 2. The available time on each project is shown in days and the average working day is shown in hours. The product of these two yields the total available hours for each project, and the summation of all projects gives 12,646 hours total available time. Major delays resulting from 15 general causes are responsible for the loss on all jobs of 4,552 hours, or 36 percent of all available time. Minor delays resulting from 9 general causes account for the loss of 1,801 hours out of 8,094 working hours—a loss of 22 percent of working time and 14 percent of available time on all jobs. Of the 12,646 available hours, but 6,293 hours are utilized in the direct production of paving mixtures.

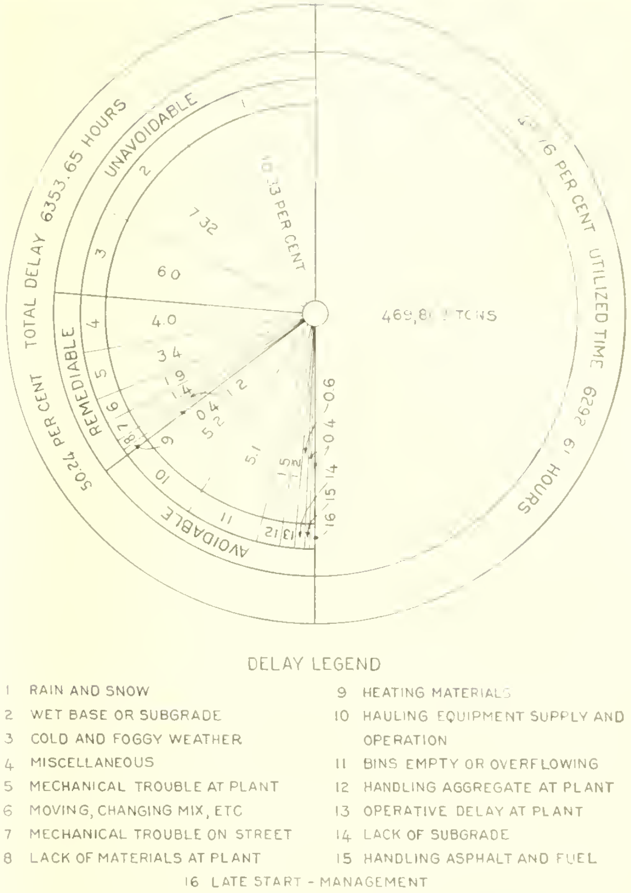


FIGURE 2.—AVAILABLE TIME DISTRIBUTED ACCORDING TO TIME UTILIZED AND TIME LOST.

Table 3 is a recapitulation of table 2, distributing all delays according to 18 general causes, and subdividing each kind of delay as unavoidable, partly remediable or avoidable. Under these heads the delays are further classified as major and minor. The last column of the table showing the number of jobs on which each type of delay occurred shows that certain well-defined types of time loss were found on nearly every project studied. The data of table 3 are shown graphically in figure 2.

EFFICIENCY OF MANAGEMENT VARIES GREATLY ON DIFFERENT PROJECTS

The extent to which production on the various projects suffered from major and minor delays combined may be shown by computing utilized time as a percentage of available time. Such percentages are given in the third column of table 4. The effect of minor delays only (utilized time as a percentage of working time) is shown in the second column. Projects are listed in the table in the ascending order of these percentages which range from 55 to 97 percent. The last column of the table shows the over-all efficiency on each of the jobs derived by computing actual utilized time as a percentage of possible utilized time (available time less unavoidable delays).

TABLE 2.—*Distribution of time losses on 23 projects*

Project number	1	2	3	4	5	6	7	8	9	10	11	12	13
Available days	75	91	48	50	73	60	41	28	40	78	81	57	36
Average day, hours	8	8	9.1	10	8	13.5	12.8	9.9	8	12.3	9.7	8	8
Total available hours	601	728	437	502	584	814	525	277	321	960	783	459	288
Major delays.	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
Rain and snow	54.2	70.5	31.0	69.0	62.7	94.6	55.0	29.5		168.7	48.3	43.4	27.0
Plant, mechanical	11.9	5.7	2.0	7.3	7.0	16.9	23.0		3.3		35.5	6.3	0.8
Street, mechanical	5.0	32.8			4.6				3.0		4.0		6.1
Late start, management	5.0				3.8		5.9						
Lack of materials		6.5	2.0		3.2			5.1		52.0	16.9	6.4	
Cold and fog			143.5	95.2									148.8
Wet base				59.1		128.7	65.2			272.8			
Moving				20.3	2.0	140.6					.5		
Hauling equipment				1.5			24.3		7.5	5.0			
Power belts					2.8								
Fuel					6.8								
Handling materials						25.8		27.0	3.3	5.5	12.3	15.7	.6
Heating materials								12.6		5.2		17.5	
Lack of subgrade										31.6	10.0		
Miscellaneous	8.0	13.0		7.3	14.6	12.4	17.7			22.6	4.0	8.9	2.7
Total	84.1	128.5	178.5	259.7	107.5	419.0	191.1	74.2	17.1	563.4	131.5	98.2	186.0
Total working time	516.9	599.5	258.5	242.3	476.5	395.0	333.9	202.8	303.9	396.6	651.5	360.8	102.0
Total working time as perecntage of available time	86.0	82.4	59.2	48.3	81.6	48.5	63.6	73.2	94.7	41.3	83.2	78.6	35.4
Minor delays:	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*
Hauling equipment	8.9	17.0	4.4	4.6	2.0	4.3	17.5	24.7	11.5	11.6	5.4	3.7	7.0
Bin shortage	8.5	12.0	7.2	10.6	4.3	8.0	15.3	14.9	9.0		6.7	12.8	10.4
Plant, mechanical	1.1	.7	.4	1.0	2.7	5.0	1.6	1.9	1.6	1.6	2.5	1.2	
Plant, operative	.1	.8	.6	4.4	1.6	3.0	1.5	2.7	1.0	2.5	1.1	2.8	2.1
Handling aggregate	5.9		.4			2.0	4.1	.6		2.2		.5	.1
Finishing					3.4								3.3
Changing or inspecting mix					.6				.5			.5	.3
Handling asphalt							1.4		4.5				.1
Miscellaneous	1.2		2.4	1.0	2.2	2.5	.7	.4		.7	2.0	1.2	.2
Total	25.7	30.5	15.4	21.6	16.8	24.8	42.1	45.2	28.1	18.6	17.7	22.7	23.5
Total minor delay, hours	133.0	183.0	39.9	52.3	80.2	97.8	140.6	91.5	85.5	73.8	115.6	81.9	24.0
Total utilized time, hours	383.9	416.5	218.6	190.0	396.3	297.2	193.3	111.3	218.4	322.8	535.9	278.9	78.0
Utilized time as percentage of—													
Working time	74.3	69.5	84.6	78.4	83.2	75.2	57.9	54.8	71.9	81.4	82.3	77.3	76.5
Available time	63.9	57.2	50.1	37.8	67.8	36.5	36.8	40.1	66.8	33.7	68.4	60.8	27.1

TABLE 3.—*Recapitulation of delays by classes, showing time lost in hours and as a percentage of available time*

Cause of delay	Class of delay												All classes		Number of projects on which delay occurred
	Unavoidable				More or less remediable				Avoidable						
	Major		Minor		Major		Minor		Major		Minor				
	Hours	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	
Rain and snow	1,307	10.3											1,307	10.3	21
Wet base or subgrade	926	7.3											926	7.3	10
Cold and foggy weather	729	5.8											729	5.8	6
Hauling equipment, supply and operation									44	0.3	613	4.9	657	5.2	23
Bins empty or overflowing											638	5.0	638	5.0	21
Miscellaneous					421	3.3	89	0.7					510	4.0	20
Mechanical trouble at plant	6	0			311	2.5	112	.9					429	3.4	23
Moving on street					198	1.6							198	1.6	10
Handling aggregate at plant									107	.8	90	.7	197	1.5	17
Mechanical on street					176	1.4							176	1.4	14
Lack of materials at plant					151	1.2							151	1.2	12
Operative at plant											146	1.2	146	1.2	23
Lack of subgrade									75	.6			75	.6	6
Handling asphalt and fuel									7	.1	46	.4	53	.5	10
Heating materials at plant					48	.4							48	.4	6
Late start management									46	.4			46	.4	8
Finishing							44	.3					44	.3	6
Inspecting or changing mix			23	.2									23	.2	7
Total major delay	2,968	23.4			1,305	10.4			279	2.2			4,552	36.0	
Total minor delay			23	.2			245	1.9			1,533	12.2	1,801	14.3	
Total major and minor delay:															
Hours	2,991				1,550				1,812				6,353		*Average*
Percent	23.6				12.3				14.4					50.3	13.5

TABLE 2.—*Distribution of time losses on 23 projects*—Continued

Project number	14	15	16	17	18	19	20	21	22	23	Total for all projects	Percentage of available time
Available days	39	29	113	28	50	114	86	102	39	42.5		
Average day, hours	8.5	11.5	8	11.8	8	8	8	8	8	8		
Total available hours	332	335	904	330	397	912	688	816	312	341	12,646	100.0
Major delays:	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	
Rain and snow	92.8	48.5	71.5	0.5		65.8	208.0	47.5	4.0	11.5	1,307	10.3
Plant, mechanical	18.1	.8	81.0		3.0	41.3	13.6	19.7	8.7	5.1	311	2.5
Street, mechanical	4.7	7.0	50.6		.3	7.3	11.8	33.2	5.6		176	1.4
Late start, management		1.0		1.4		12.0		9.9	7.0		46	.4
Lack of materials		1.5	6.0			47.4			3.3	.7	151	1.2
Cold and fog	111.1		9.5			220.9					729	5.8
Wet base	27.0	65.8	41.7				135.9	113.8	16.0		920	7.3
Moving		3.3		3.5	1.4	4.7	16.3	5.4			198	1.6
Hauling equipment		2.3		.8			.3	2.3			44	.3
Power belts					1.8					1.4	6	
Fuel					.2						7	.1
Handling materials		6.5			2.3		4.8	3.2			101	.8
Heating materials		7.3			3.7					1.7	48	.4
Lack of subgrade		6.8	18.2		.7			7.7			77	.6
Miscellaneous	5.3	1.5	250.5	8.9			.5	43.1			421	3.3
Total	259.0	152.3	529.0	15.1	13.4	399.4	391.2	285.8	44.6	23.4	4,552	36.0
Total working time	73.0	182.7	375.0	314.9	383.6	512.6	296.8	530.2	267.4	317.6	8,094	
Total working time as percentage of available time	22.0	54.5	41.5	95.4	95.6	56.2	43.1	65.0	85.7	93.1	64.0	
Minor delays:	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Hours*	
Hauling equipment	3.9	9.9	3.9	16.7	1.5	4.9	3.0	7.5	1.2	0.1	613	4.9
Bin shortage	5.2	6.7	18.5		9.1	3.5	1.8	8.8	9.1	1.0	638	5.0
Plant, mechanical	.1	2.7	1.2	2.5	.9	.3	.5	.1			112	.9
Plant, operative	1.1	2.1	1.6	1.8	1.5	3.1	2.5	2.4	2.0	.7	146	1.2
Handling aggregate	.5	8.7	.8						1.9		90	.7
Finishing	2.7				1.5			2.4		1.3	44	.3
Changing or inspecting mix		2.7	1.5		1.6						23	.2
Handling asphalt	3.7	6.0	.2			1.6	1.6				46	.4
Miscellaneous						.5	5.4	1.3	1.9		89	.7
Total	17.2	38.8	27.7	21.0	16.1	13.9	14.8	22.5	16.1	3.1	*Percentage* 22.3	14.3
Total minor delay, hours	12.5	70.8	103.8	66.2	61.8	71.0	43.8	119.3	43.0	9.7	1,801	
Total utilized time, hours	60.5	111.9	271.2	248.7	321.8	441.6	253.0	410.9	224.4	307.9	6,293	
Utilized time as percentage of—												
Working time	82.8	61.2	72.3	79.0	83.9	86.1	85.2	77.5	83.9	96.9	77.7	
Available time	18.2	33.3	30.0	75.4	81.1	48.4	36.8	50.4	71.9	90.3	49.8	

The over-all efficiency for the average job is computed as follows:

		Hours
Available time		12,646
Unavoidable delay:		
Major	3,889	
Minor	228	
		4,117
Possible utilized time		8,529
Avoidable delay:		
Major	663	
Minor	1,573	
		2,236
Actual utilized time		6,293
Actual utilized time as a percentage of possible utilized time		74

These data are shown graphically in figure 3. The upper graph shows the distribution of available time between the two kinds of delays and productive work. The lower graph shows the distribution of working time between minor delays and productive work and a comparison of over-all efficiency at the various plants. The close agreement of utilized time as a percentage of working time with over-all efficiency indicates that the minor delays were largely avoidable and that the major delays were largely unavoidable.

These data are an index of the efficiency of management in making use of available time. However, they do not reflect the mechanical efficiency of the plants while in full production.

TABLE 4.—*Utilized time as a percentage of available time and of working time and over-all efficiency at all plants*

Job no.	Utilized time as a percentage of working time	Utilized time as a percentage of available time	Total working time as a percentage of available time	Over-all efficiency
	Percent	*Percent*	*Percent*	*Percent*
8	55	40	73	46
7	58	37	64	52
15	61	33	55	56
2	69	57	82	69
9	72	67	95	71
16	72	30	42	66
1	74	64	86	75
6	75	37	49	65
13	77	27	35	76
12	77	61	79	71
21	78	50	65	73
4	78	38	48	76
17	79	75	95	80
10	81	34	41	67
11	82	68	83	81
14	83	18	22	81
5	83	68	82	84
18	84	81	97	85
22	84	72	86	82
3	85	50	59	86
20	85	37	43	89
19	86	48	56	78
23	97	90	93	96

The frequency and extent of delays from a variety of causes warrants a detailed discussion of the manner in which they creep into highway construction operation either as a result of adopted practices of management, or as a result of circumstances not directly controlled by management. Discussion of these matters will be delayed in order to first consider other losses which are

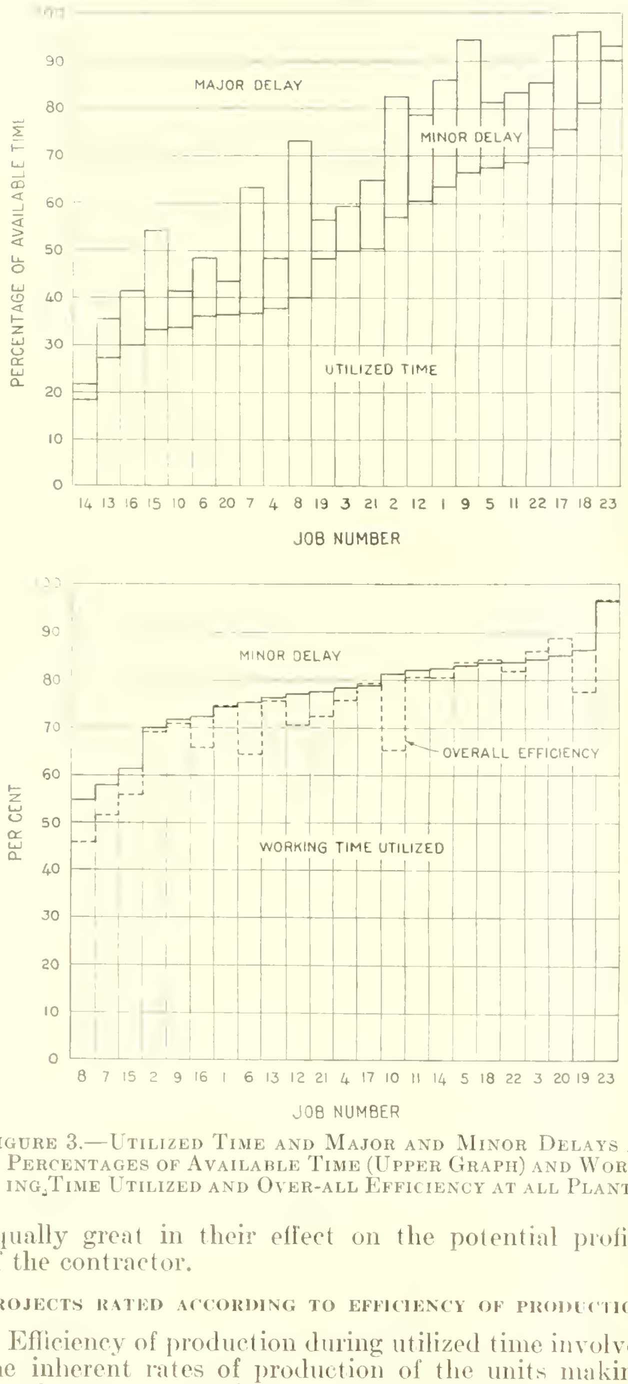


Figure 3.—Utilized Time and Major and Minor Delays as Percentages of Available Time (Upper Graph) and Working Time Utilized and Over-all Efficiency at all Plants.

equally great in their effect on the potential profits of the contractor.

PROJECTS RATED ACCORDING TO EFFICIENCY OF PRODUCTION

Efficiency of production during utilized time involves the inherent rates of production of the units making up the plant, practices in operating the plant and specification requirements. Table 5 shows details concerning the mixing cycles on each of the 23 jobs, the output of the plants and their over-all efficiency. The mixing cycles shown represent the actual average performance during utilized time.

Mixing cycles range from 46.8 seconds to 87.4 seconds with the corresponding batches per hour ranging from 76.9 to 41.2. The plant with the smallest batch (0.309 ton) had a mixing cycle of 58.6 seconds with a resulting possible output of 19 tons per hour. A plant producing batches in excess of 2 tons in a cycle of 49.2 seconds, had a possible output of 150 tons per hour or 8 times the amount of the smaller plant.

In table 5 the total job tonnage and the utilized time (table 2) are used to determine the rate of production per utilized hour. Since utilized time represents operation at maximum efficiency, this figure also represents maximum possible production or plant capacity. Working hours and total tons produced are used to determine the production per working hour. The percentage of plant capacity attained is the same as the percentage of working time utilized. Production per available hour is also shown. The over-all efficiencies, which reflect the management's use of available time exclusive of unavoidable delays are repeated from table 4 for comparative purposes.

The production of a plant depends on both the inherent limitations of the plant equipment and on the efficiency with which it is operated. An index of production may be obtained by multiplying the plant capacity in tons per hour by the over-all efficiency. Such an index for each plant is shown in table 6, which is arranged in descending order of indices. If the job with the highest index of production, no. 23, be accepted as having maximum production, or 100 percent, we can then compute the percentage of maximum attained on the other projects as shown in the table.

The production of job no. 23, as controlled by the combined plant and management characteristics was 2½ times that of the average and 11 times that of job no. 10. A later section of the report will show that the unit costs for labor and equipment on each project are in substantially the same order as the indices of production. Job no. 23 was a large project and used a large plant, and it should not be assumed that every project should use such a plant or should attain 100 percent on the basis used in table 6.

The data of table 5 are shown graphically in figure 4 in which the jobs are arranged in numerical order. The upper diagram shows the time of charge, mixing, and discharge for each plant. The middle diagram is a comparison of batch size with a superimposed comparison of the possible batches per hour at each plant—the two factors which determine the possible output. The lower diagram shows the rates in tons per utilized hour, per working hour, and per available hour. These rates are also referred to as plant capacity, attained production, and gross production. These rates cover production on whole road projects and therefore represent average characteristics.

RATES OF PRODUCTION ON THREE PROJECTS COMPARED

In a study of production with a view to increasing efficiency we must go beyond average characteristics and examine the fluctuations in output from day to day. Good management will be reflected by a consistent high daily production while inefficient management which permits delays to creep in will show fluctuations.

Figure 5 shows the cumulative rates of production during working time expressed as a percentage of the maximum possible rate on each day of operation on three typical projects. The figures for any day represent the average for all days up to and including that day. There is a marked difference in the general average rates attained at the three plants, which are affected by the size of the plant, specification requirements as to the mixing cycle, and the efficiency of management. The projects were selected particularly to show variations in the effect of fortuitous conditions.

TABLE 5.—*Operating characteristics and efficiency of plants studied*

Job no.	Operating characteristics of mixer				Possible batches per hour	Average batch	Possible production per hour	Production during study	Attained production per working hour	Ratio of attained production to plant capacity	Production per available hour	Over-all efficiency
	Charge	Mix	Discharge	Cycle								
	Seconds	*Seconds*	*Seconds*	*Seconds*		*Tons*	*Tons*	*Tons*	*Tons*	*Percent*	*Tons*	*Percent*
1	9.2	43.3	10.5	63.0	57.1	1.174	67.1	25,752	49.8	74.3	42.8	74.6
2	11.1	45.4	12.8	69.3	51.9	1.333	69.2	28,831	48.1	69.5	39.6	69.3
3	10.7	59.0	14.6	84.3	42.7	.599	25.6	5,599	21.6	84.4	12.8	86.3
4	8.1	51.6	3.4	63.1	57.1	.987	56.3	10,705	44.2	78.5	21.3	75.7
5	8.4	39.8	9.8	58.0	62.1	1.566	97.3	38,526	80.9	83.1	66.0	84.2
6	18.6	35.6	5.0	59.2	60.8	.487	29.6	8,807	22.3	75.4	10.8	64.5
7	7.3	38.5	4.0	49.8	72.3	.923	66.8	12,918	38.7	57.9	24.6	51.6
8	8.2	34.8	3.8	46.8	76.9	.523	40.2	4,460	22.0	54.8	16.1	45.7
9	14.0	40.0	8.0	62.0	58.1	1.819	105.7	23,086	75.9	71.9	71.9	70.9
10	12.5	34.3	11.8	58.6	61.4	.309	19.0	6,144	15.5	81.5	6.4	65.1
11	8.1	38.9	4.2	51.2	70.3	.495	34.8	18,658	28.6	82.2	23.8	80.7
12	10.4	41.5	11.4	63.3	56.9	1.188	67.6	18,840	52.2	77.3	41.0	70.8
13	10.8	61.0	9.2	81.0	44.4	.690	30.7	2,393	23.5	76.5	8.3	75.8
14	5.4	72.1	9.9	87.4	41.2	.659	27.1	1,638	22.5	82.9	4.9	80.6
15	10.6	56.6	5.6	72.8	49.5	1.124	55.6	6,198	34.0	61.2	18.5	55.9
16	7.0	41.3	10.0	58.3	61.7	1.523	94.1	25,496	68.0	72.3	28.2	65.5
17	10.0	42.7	8.0	60.7	59.3	.552	32.8	8,148	25.9	79.0	24.7	79.5
18	12.1	33.0	13.7	58.8	61.2	2.035	124.6	40,103	104.5	83.9	101.0	84.5
19	10.0	40.3	13.2	63.5	56.7	1.956	110.9	48,950	95.5	86.1	53.7	77.7
20	8.2	43.4	13.8	65.4	55.0	1.262	69.4	17,554	59.1	85.2	25.5	88.9
21	6.0	40.0	12.2	58.2	61.8	1.563	96.6	39,685	74.8	77.5	48.6	72.6
22	10.8	24.2	14.2	49.2	73.2	2.055	150.4	33,756	126.2	83.9	108.2	82.2
23	9.8	31.3	14.5	55.6	64.8	2.186	141.7	43,556	137.4	97.0	127.9	96.2
Average or total	9.9	43.0	9.7	62.6	57.5	1.299	74.7	469,803	58.4	78.2	37.1	73.9

TABLE 6.—*Indices of production and comparison of production based on assumption that maximum production was attained on job no. 23*

Job	Index of production	Percent of maximum	Job	Index of production	Percent of maximum
23	136.2	100.0	4	42.7	31.3
22	123.8	90.0	7	34.5	25.3
18	105.2	77.3	15	31.1	22.8
19	86.1	63.2	11	28.1	20.6
5	81.9	60.1	17	26.1	19.2
9	75.0	55.1	13	23.3	17.1
21	70.2	51.5	3	22.1	16.2
20	61.7	45.3	14	21.9	16.1
16	61.6	45.2	6	19.1	14.0
1	50.1	36.8	8	18.4	13.5
2	47.9	35.2	10	12.4	9.1
12	47.8	35.1			

Table 7 shows for each of these three jobs the factors controlling production as actually recorded during working hours and as specified or interpreted in practice. On some of the jobs studied the specifications required a standard mixing time and also limited the number of batches per working hour at a rate not in harmony with the mixing time—a double standard frequently encountered in this class of work. On the projects studied the limitation on batches per hour was the one usually enforced. Lack of adequate devices for timing the mixing period and the consequent lack of control is the probable cause of the limitation of batches per hour. On recent projects, satisfactory timing devices have been in use and there appears no need for additional limitation.

On job no. 4 different mixing times were specified for base and surface course. With the necessary charge and discharge time the average cycle (specified) was 56 seconds, which permitted 64.3 batches per hour. The mixer was designed for a 1-ton batch, which limited production to 64.3 tons per hour.

On job no. 18 the specification, as interpreted, permitted a mixing time plus one half the discharge time of 45 seconds or alternately a maximum rate of 65 batches per hour. The latter requirement governed. Using a 2-ton batch for which the mixer was designed gave a maximum permissible rate of 130 tons per hour.

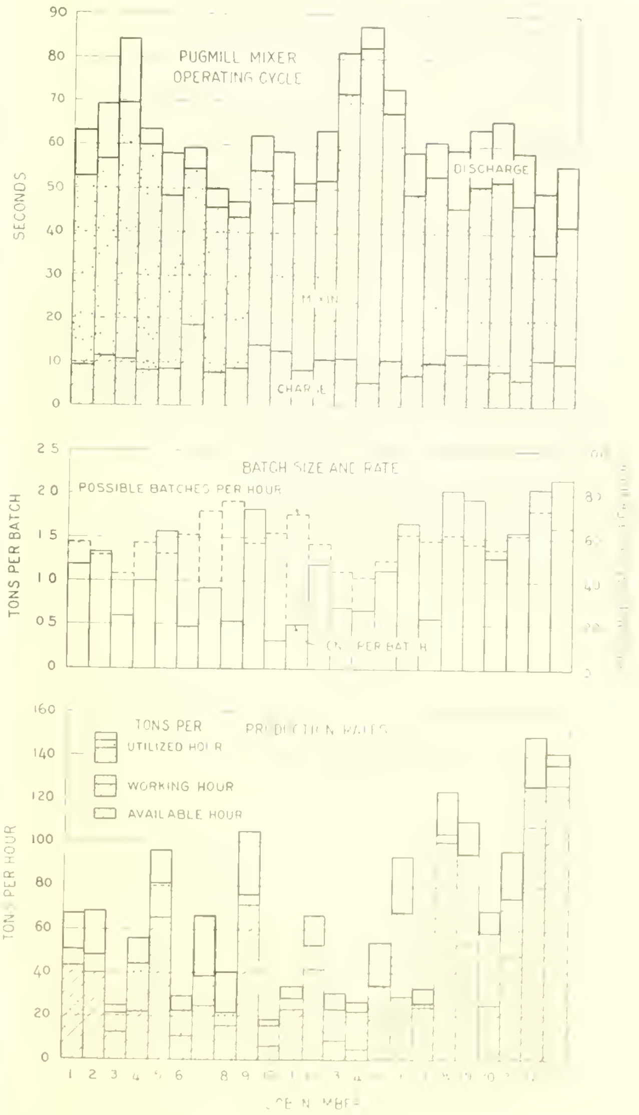


FIGURE 4.—EFFECT OF OPERATING CYCLE AND BATCH SIZE ON PRODUCTION RATE.

TABLE 7.—*Factors controlling production at 3 plants whose production rates are shown in figure 5*

	Actual limitations			Specified or plant limitation		
	Base	Surfacing	Total or average	Base	Surfacing	Total or average
Project no. 4						
Charge, seconds	7.2	8.6	8.1	7.2	8.6	7.9
Mix, seconds	33.5	60.7	51.6	30.0	60.0	44.6
Discharge, seconds	4.0	3.0	3.4	4.0	3.0	3.5
Cycle, seconds	44.7	72.3	63.1	41.2	71.6	56.0
Batches per working hour	63.2	39.1	44.8	87.4	50.3	64.3
Tons per batch	.944	.889	.987	1.0	1.0	1.0
Tons per working hour	59.6	34.7	44.2	87.4	50.3	64.3
Working hours	92.2	150.0	242.2	62.9	103.5	166.4
Total tons	5,497	5,208	10,705	5,497	5,208	10,705
Project no. 18						
Charge, seconds	9.9	14.3	12.1	9.9	9.9	9.9
Mix, seconds	44.6	46.4	44.4	32.2	31.4	31.8
Discharge, seconds	13.3	14.1	13.7	13.3	14.1	13.7
Cycle, seconds	67.8	74.8	70.2	55.4	55.4	55.4
Batches per working hour	53.1	48.1	51.3	65	65	65
Tons per batch	2.048	2.009	2.035	2.0	2.0	2.0
Tons per working hour	108.8	96.8	104.5	130	130	130
Working hours	246.0	137.6	383.6	205.9	102.5	308.4
Total tons	26,776	13,327	40,103	26,776	13,327	40,103
Project no. 22						
Charge, seconds	8.6	14.7	10.8	8.6	8.6	8.6
Mix, seconds	33.6	33.9	33.7	29.0	36.5	31.8
Discharge, seconds	13.8	14.9	14.2	13.8	14.9	14.2
Cycle, seconds	56.0	63.5	58.7	51.4	60.0	54.6
Batches per working hour	64.3	56.7	61.3	70.0	60.0	66.0
Tons per batch	2.056	2.053	2.055	2.1	2.1	2.1
Tons per working hour	132.2	116.5	126.2	147.0	126.0	138.6
Working hours	163.1	104.3	267.4	146.9	96.5	243.4
Total tons	21,593	12,163	33,756	21,593	12,163	33,756

On project no. 22 the specification as interpreted required 45 seconds mixing time or alternately permitted 70 batches per hour on base and 60 on surface course. With a 2.1-ton batch the maximum permissible rate (average for two courses) was 138.6 tons per hour. There is a great difference in the efficiency with which these plants were operated. On project no. 22 the cumulative rate of production rose to 90 percent of the maximum within 7 days after beginning work, and the job was completed in 39 days with an average rate of 91 percent. On project no. 18 the average rate for the job was slightly more than 80 percent.

On project no. 4 work was greatly hampered by bad weather and the cumulative rate of production did not reach 70 percent until the twenty-ninth day and remained at approximately this figure for the remainder of the job. The plant on project no. 18 could have completed this project in 10 days.

A combination of time losses, slow operation, and small plant reduced the output at one plant to 4.9 tons per available hour (see table 5) even though operating at 80.6 percent efficiency, while another plant reached five times that production while operating at 51.6 percent efficiency. Still another project produced 108.2 tons per available hour with an efficiency of 82.2 percent.

The low rates of production attained at some plants indicate that not only should more attention be given to the elimination of avoidable time losses but that consideration should be given to the use of plants of larger capacity. Time losses due to weather cannot be controlled, but when such losses are followed by production which cannot exceed a fixed low rate the unit costs are certain to be high. The desirable size of plant will be affected by fixed daily cost of the outfit, relative plant costs, size of project, and other matters. Equipment and practice is not yet sufficiently standardized to attempt to lay down rules for size of plant but it is quite evident that many jobs justify greater plant capacity with a consequent greater daily production during available time.

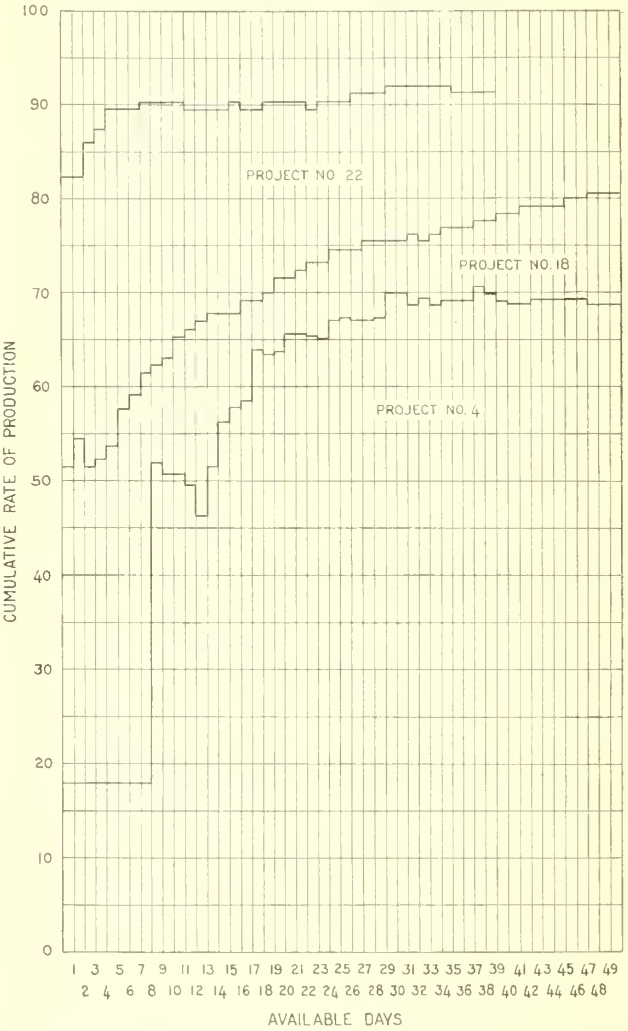


FIGURE 5.—CUMULATIVE RATES OF PRODUCTION AT 3 PLANTS DURING WORKING TIME EXPRESSED AS PERCENTAGE OF THE MAXIMUM POSSIBLE RATE. THE PLANT ON PROJECT NO. 4 WAS SMALL, POORLY MANAGED, AND WEATHER CONDITIONS WERE BAD. ON PROJECT NO. 18 THE PLANT WAS LARGE, WELL MANAGED, AND WEATHER CONDITIONS WERE GOOD. ON PROJECT NO. 22 THE PLANT WAS LARGE AND WELL MANAGED BUT WEATHER CONDITIONS WERE ONLY FAIR.

LOSSES OF TIME DUE TO WEATHER DISCUSSED

Referring to tables 2 and 3, it will be noted that 23.4 percent of all available time is lost because of the weather and that such delays occurred on 21 out of the 23 projects. Delays due to rain, snow, wet base or subgrade, and cold or foggy weather, are classed as major unavoidable delay. However, there is the possibility of minimizing their effect on production and unit cost by adjusting the construction season in accordance with weather records.

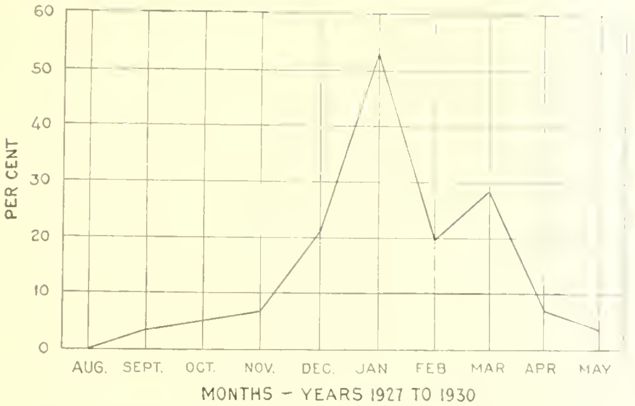


Figure 6.—Percentage of Available Time Lost Because of Weather Conditions on California Projects, 1927 30.

States should and do cooperate with the contractors in the letting of contracts so as to permit construction of high-type surfacing during the most advantageous seasons of the year. Periods of greatest freedom from time loss due to weather conditions may be determined for sections of the country as shown by figure 6. This chart shows the percentage of available time lost due to weather on California projects and for all months except June and July. The data were collected in the years 1927 to 1930 and the observations covered from 300 to 1,000 available hours in each month. No data were collected for the months of June and July. It is believed that the chart is fairly accurate for most coast and San Joaquin Valley points. The months between April and November, inclusive, had relatively favorable weather for construction. Such data can be developed for any section of the United States and the records of the United States Weather Bureau are particularly useful for such purpose.

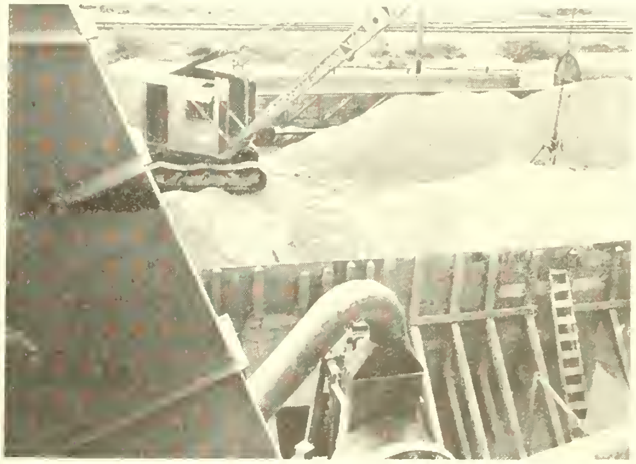
Weather losses occur almost invariably as major delays, and halt rather than retard operations. On the projects studied only 76 percent of the time available could be used as working time. Other losses which also detract from available time are found in both the major and minor classifications. Late starts in the morning and at noon and occasional early stops are not tolerated under competent supervision. A regular and consistent working day should be the rule. The occasional practice of working extra hours to make big runs one day only to suffer a corresponding loss the following day is not recommended. Asphalt paving construction requires a high degree of consistency since costs for such items as hauling units and heating of materials continue through all short delays.

The orderly delivery of purchased materials is at times beyond the control of management but frequently lapses in placing orders are observed and a loss from this cause is clearly avoidable. In one case, laxity in inspection of plant requirements led to failure of the fuel supply. In other cases failures of belt and bucket lines were not anticipated or failure to maintain a proper inventory of spare parts resulted in prolonging delays. In general, such delays have been classified as partly remediable. Their prevalence indicates that the plant management should definitely place responsibility among employees for keeping up stocks of materials, supplies and spare parts, and anticipating breakdowns of units.

Preventable or partly remediable delays were recorded on more than half of the projects studied. Uncommon delays, principally accidental in character but not infrequently due to carelessness also resulted in loss of production. The explosion of a boiler, destruction of plant by fire in two cases and the accidental death of an employee are typical examples. These were classed as miscellaneous delays.

All these delays, common and uncommon, fortuitous or otherwise, indicate the need for alertness, since they robbed 23 contractors of 12.3 percent of their available time.

The total loss of 4,553 hours on 23 projects because of major delays is a serious one. However, major delays generally result in cessation of operation, and are therefore usually accompanied by a partial reduction in cost of labor, fuel, etc. With minor delays such is not the case. Minor delays appear in the countless repetitive operations where a single loss of time is of negligible moment but when regularly repeated they amount to a considerable portion of the working time. They occur under full operating costs and are of greater importance than idling costs to the extent that hourly operating costs exceed hourly idling costs. Most minor delays are avoidable.



Materials Yard, and Arrangement of Bulkheads. Dust Collector in Foreground.

"BIN DELAYS" OUTSTANDING AS A CAUSE OF MINOR DELAYS

The outstanding minor delay is "bin shortage" caused by inability to furnish aggregate to multiple bins in the proportions required in the mix. Failure to do this results in shortage in one bin or overflow in another. Bin shortage accounted for the loss of more than 613 hours on the 23 jobs and was found on every project. On recent jobs under good management definite steps were taken to reduce this loss with excellent results.

When aggregates are fed to the elevator in proportions differing from those required in the mix a shortage is bound to follow in one bin or overflow in another. Where the different sizes of aggregate are combined when delivered or are combined in stock piles or bunkers at the plant there is always more or less trouble with bin supply. Complete separation of each required size in stock piles is a first essential to the necessary control. With the necessary sizes readily available the problem can be completely solved by proper functioning of feed controls.

Figure 7 shows several different methods of feeding aggregates to elevators. At one plant the method of handling was as follows (method A, fig. 7): Four sizes of aggregate were required. The materials were stored at ground level against a bulkhead with 2 partitions to provide 3 bunkers. Sand and the largest size of rock were combined in 1 of these bunkers according to the judgment of the crane operator while the other 2 were filled with correctly separated sizes. Adjustable vertical gates in the bulkhead permitted materials to flow to a pit where they were picked up by the "cold elevator." The gates were adjusted from time to time as the need was indicated. Bin conditions were indicated by a system of rope "feelers" and visual signals.

The sand was mixed with coarse rock to overcome the resistance of sand to flow. The control of the two mixed sizes was not positive and the feeding of the small stone through vertical gates was not entirely satisfactory.

Another plant was operated on the same general plan except the sand was stored in a separate bunker with a sand trap feeding a belt conveyor which deposited the sand in the elevator pit (method B, fig. 7). Here there was also difficulty with the vertical gates and a need for constant alertness in regulating the controls.

Improved operation was observed at a third plant with four raised bunkers feeding a belt conveyor in front of the stone bunkers and beneath the sand bunker (method C, fig. 7). Sand was fed through a trap and stone through angular sloped feed gates. Rate of feed from bunkers could be observed while inspecting the condition of bins a considerable advantage. Such an installation costs more than those previously described but the cost was more than offset by the saving in working time.

A fourth method gives such positive control as practically to eliminate bin delays (method D, fig. 7). It consists of four bunkers placed over an excavated and shored tunnel in which a belt conveyor is placed. Each bin has two gates in the bottom which are used alternately to induce breaking down of reposed material. The open gates drop the material to an automatic, power-driven plate feeder which can be set to deliver material in the exact quantity desired. On the job where this arrangement was used it practically eliminated bin delays and the savings thus effected were considerably more than the cost of the installation. In 100 hours of operation bin delay amounted to less than one tenth of 1 percent.

DELAYS FROM SHORTAGE OF HAULING EQUIPMENT OF CONSIDERABLE IMPORTANCE

Next in importance to bin delay is the time loss arising from a shortage of hauling equipment or faulty operation of hauling units. Some loss of this type occurred on every project and such losses accounted for 657 hours on all projects or 5.2 percent of the total available time. Time losses arising from hauling are thought to be largely avoidable since they occur most extensively on poorly managed work. Referring to table 2 it will be noted that on 4 poorly managed jobs, hauling equipment delay varied from 16 percent to 24 percent of operating time, whereas on 4 well managed projects, it was reduced to less than 2 percent and on one of these jobs to less than one tenth of 1 percent.

Frequently, it is difficult to determine whether a delay is the result of shortage of hauling units or to road conditions. Timing of the hauling units should indicate the source of the trouble and the remedy to be applied.

Delay resulting from hauling operations may have its origin in faulty plant arrangement, failure to provide sufficient storage of mixed batches, poor and indifferent

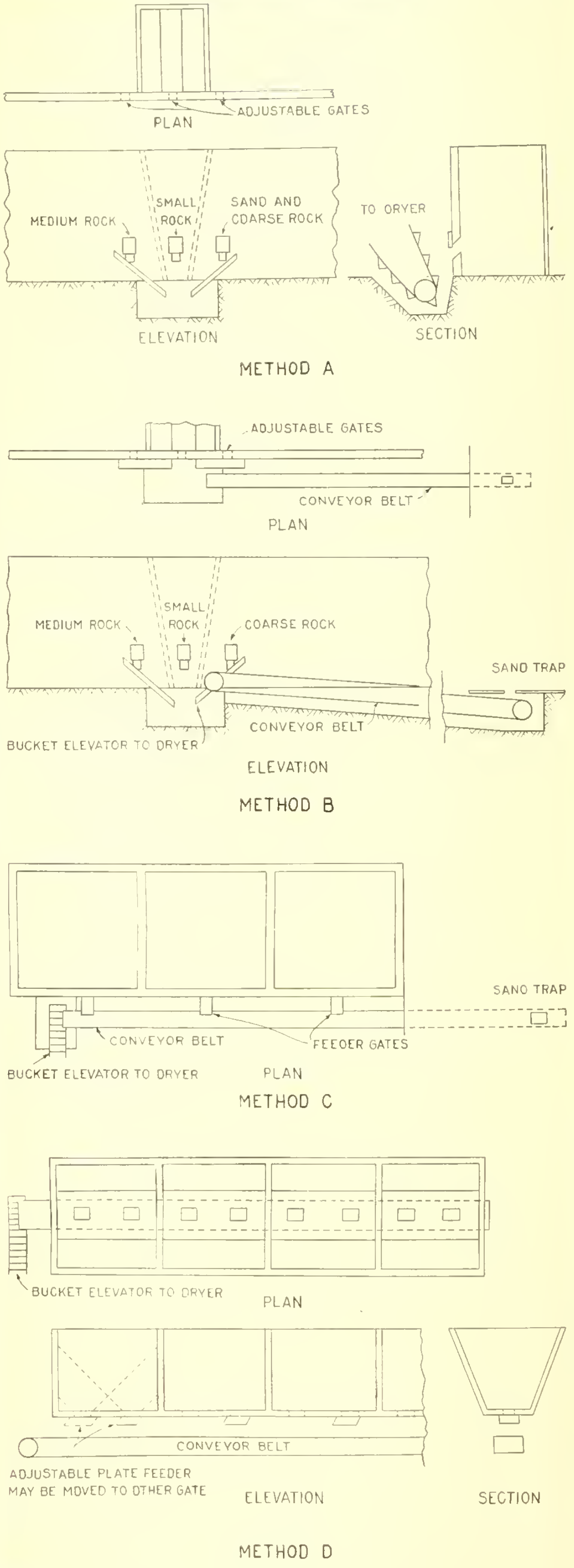


Figure 7.—Methods of Feeding Aggregate to Elevator.

operators, poor equipment, bad roads, traffic interference, lack of correlation between plant and road capacity, or may be due to an insufficient number of hauling units.

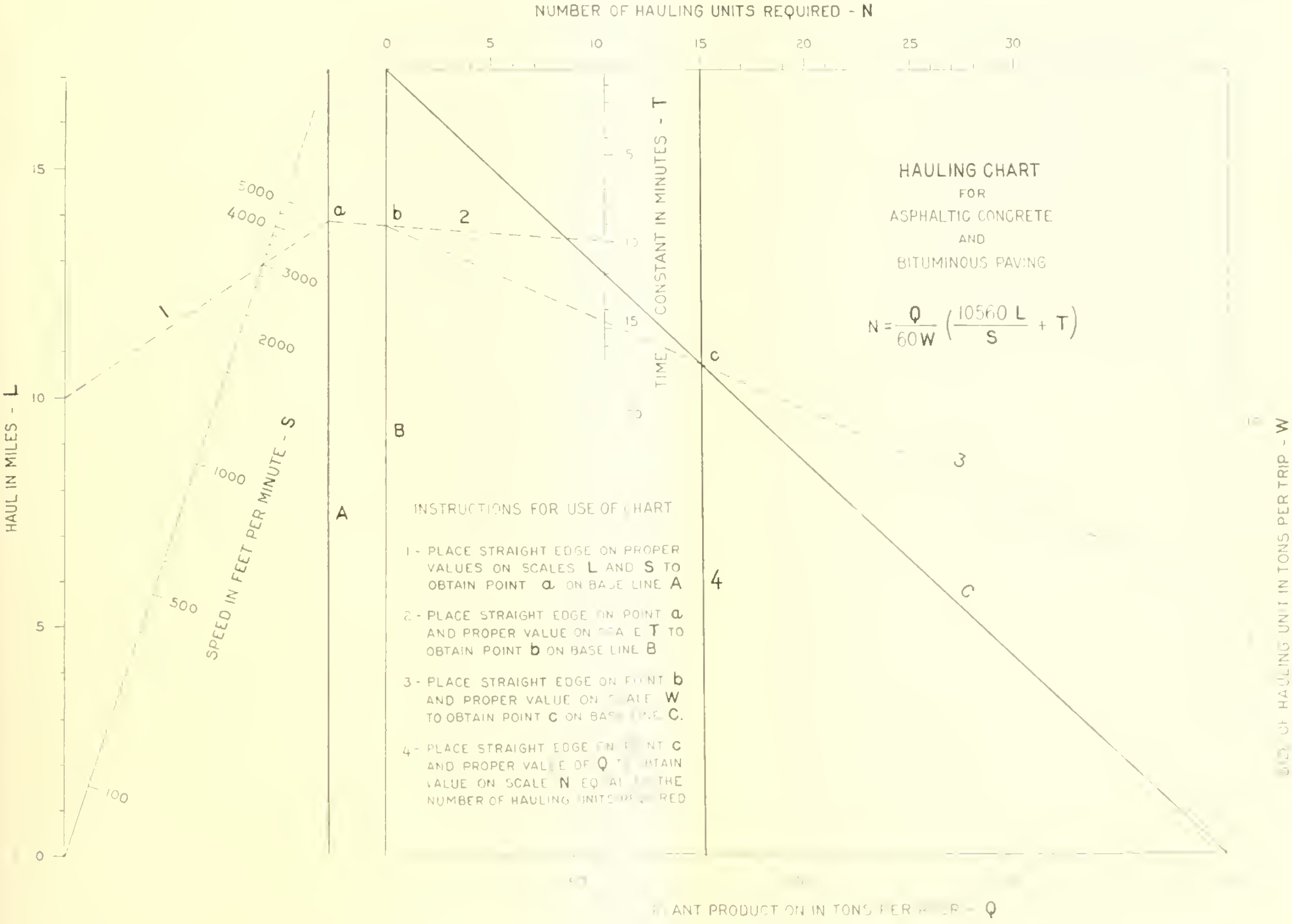
The routine operation of taking on the load at the plant should be smooth and systematic. Oiling of bodies should be done at necessary stops on the plant loop. Nearly all plants are equipped for storage of one or more truck loads of mixed material, but some contractors delay truck operation by requiring trucks to wait and receive batches as they are mixed. Trucks should pass over a loop at the plant and should not be required to back in turning or to reach the loading point. Scales for weighing should be on the most direct route from the plant to the job. Experienced mechanics should be at hand to promptly correct mechanical troubles with the hauling equipment. Roads should be regularly maintained and some conditions may require constant maintenance. The value of increased travel speed will more than pay maintenance costs.

Equipment and personnel on the street or road should be sufficient to handle the production of the plant without delaying trucks in depositing loads.

Often, failure to provide an adequate supply of hauling equipment is due to inability to determine needs rather than to inability to obtain an ample supply. To assist in rectifying this condition, contractors are frequently furnished hauling charts, graphically simplifying the determination of a proper supply. Figure 8 is a Z-type nomograph designed particularly for use on asphaltic concrete work and based on the formula $N = \frac{O}{60W}\left(\frac{10{,}560L}{S} + T\right)$. The symbols are defined below. Instructions for use are given on the chart and the steps in the progressive solution are numbered correspondingly. The application of this chart to a specific problem is shown by guide lines. To arrive at a solution for a particular job it is necessary to know the length of haul, L; the usual average round-trip speed of units on the road, S; the time constant which is the total time consumed in performing necessary operations other than travel, T; the capacity of the hauling unit, W; and the plant capacity, O. The number of trucks required for any length of haul up to 17 miles may be determined with this chart.

The shorter the haul the larger is the relative importance of the time constant. Large hauling units have a greater time constant but the frequency of occurrence is less. Figure 8 may also be used to determine the economical size of hauling unit. The number of trucks required may be determined for alternative sizes, using the operating constants for each size of truck. Knowing the number of trucks required the total cost may be determined from the cost of ownership or rental of each size. On the projects studied, loads carried varied from 1.17 tons to 6.57 tons and the lowest unit cost was produced by the largest trucks.

Hauling cost is sufficiently important to justify analysis before the job is begun. Careful advance planning is very likely to result in substantial savings.



INSTRUCTIONS FOR USE OF CHART

1 - PLACE STRAIGHT EDGE ON PROPER VALUES ON SCALES L AND S TO OBTAIN POINT a ON BASE LINE A

2 - PLACE STRAIGHT EDGE ON POINT a AND PROPER VALUE ON SCALE T TO OBTAIN POINT b ON BASE LINE B

3 - PLACE STRAIGHT EDGE ON POINT b AND PROPER VALUE ON SCALE W TO OBTAIN POINT C ON BASE LINE C.

4 - PLACE STRAIGHT EDGE ON POINT C AND PROPER VALUE OF Q TO OBTAIN VALUE ON SCALE N EQUAL TO THE NUMBER OF HAULING UNITS REQUIRED

Figure 8.—Diagram for Determining Number of Hauling Units.

The possible economy of an extra plant set-up for the purpose of reducing average haul distance should be investigated. It should be borne in mind that total hauling cost is the summation of daily costs while hauling at varying distances and that calculations based on the average haul distance are misleading. Occasionally it has been found uneconomical to furnish the hauling equipment necessary to maintain full plant production on extremely long hauls. However, it is believed that a careful comparison of the cost of an additional plant set-up with the additional hauling costs and losses in plant production will often indicate the desirability of moving the plant in such cases.

MANY MINOR DELAYS CAN BE EITHER MINIMIZED OR PREVENTED

A Typical Dryer Arrangement.

Delays at the plant include those classed as "mechanical" or failure of machinery to function properly; "operative" or failure of labor to function properly; "handling aggregate" (exclusive of bin delays); interruption of operation to inspect or change the mix; and a variety of miscellaneous short delays of infrequent occurrence. Such minor delays accounted for a total of 4.34 percent of all working time, a matter of 550 hours.

Many mechanical failures could not reasonably have been anticipated. However, careful, periodic inspections will accomplish a definite reduction in the frequency of breakdowns. The maintenance of carefully inventoried stocks of repair parts such as chain links, belt laces, pipe line connections, cables, dipper or clamshell teeth and gear sprockets has proven to be low-premium insurance.

Operative delays occur as the result of failure of a particular machine to keep up with the pace which can be set on the rest of the job and may be due to inadequacy if the machine itself or to the manner in which it is operated. A study of time records is convincing that the majority of such delays are the result of habits of operators which can be corrected. It is as easy for operators to form the habit of consistently maintaining output at the capacity of the machine as it is to fall into careless operation which is perhaps affected by another equally careless operator at another machine. Such operation is most often due to lack of thought rather than indifference. The high cost of operative delays makes it desirable to place skillful operators in key positions at wages commensurate with the responsibility of the position.

Delays incident to handling materials may occur at any point along the line of progress through the plant. Adequate crane capacity is essential and must be accompanied by good operation or output will suffer. A poor machine with a good operator or a good operator and machine with a poor arrangement of facilities for unloading, stock piling and feeding to the dryer, may fix the limit of production considerably below that attainable in other parts of the plant. Reference is again made to figure 1 which shows a typical, orderly arrangement with the crane runway between spur track and stock piles and within easy reach of all sizes of aggregate. With proper arrangement of facilities, the ordinary ¾-yard crane is suitable for production up to 1,200 tons in an 8-hour day of plant operation.

MANY DRYERS FOUND TO PRODUCE UNSATISFACTORY RESULTS

Delays at the dryer may result from the use of a dryer of inadequate capacity, or from the use of excessively moist material. Dryer capacity depends on a number of variables and calculations of capacity are based on an empirical formula. Table 8 shows the dimensions and characteristics of dryers at 11 of the plants studied.

Examination of the data shows that the capacity of a dryer is, to a considerable extent, dependent upon the degree of agitation of the material. Agitation is affected by the details of the dryer design and particularly by the baffling which controls the height of fall. Table 9 demonstrates this relationship.

Table 8.—*Characteristics of typical dryers*

Job no.	Length	Diameter	Pitch	Revolutions per minute	Empirical capacity in tons per hour under various conditions		
					Poor	Average	Good
	Feet	*Inches*	*Inches per foot*				
1	24.0	66	0.88	9.7	70	90	110
2	20.5	60	.75	10.3	60	70	90
5	18.0	60	1.00	6.6	60	75	95
9	24.0	72	.76	5.3	70	90	110
16	24.0	54	1.00	9.5	65	85	100
18	22.0	72	.75	8.0	97	124	150
19	22.0	72	.85	7.0	83	108	135
20	23.0	60	1.00	7.7	70	90	110
21	20.5	60	1.25	7.0	60	70	90
22	22.0	72	.75	8.0	97	124	150
23	22.0	72	.75	8.0	97	124	150
Average	22.0	66	.89	7.9	75	95	117
Typical	24.0	72	.75	8.0	90	120	150

Table 9.—*Relation between height of fall of material in the dryer and output at 4 typical plants*

Height of fall of material	Capacity per hour	Material in dryer at any instant	Time required to produce a ton of material
Feet	*Tons*	*Tons*	*Seconds*
3.48	150	5.21	24.0
2.82	118	6.72	30.5
2.11	89	2.42	40.8
1.25	69	1.17	52.2

Efficiency of dryer operation is to be judged not only by rate of output but also by the temperature of the materials as they leave the plant. Variations in the temperature of mixed materials affect every operation in laying the surface and frequently result in lack of smoothness and density. Samples of compacted pavement of the same mix have shown a percentage of voids ranging from 7 to more than 16. The excessive void content was attributed to low temperature during compaction. Figure 9 shows the average and extreme temperatures of batches leaving the plant on five jobs.

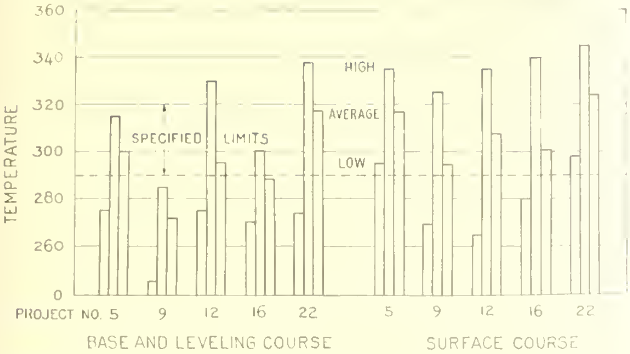


Figure 9.—Average and Extreme Temperatures of Loads Leaving Plant on Five Projects.

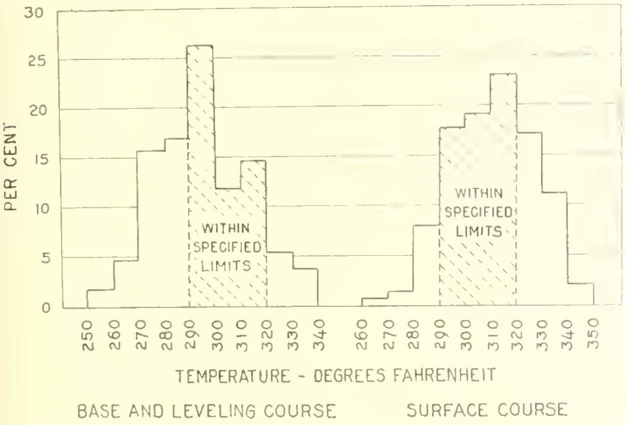


Figure 10.—Daily Average Temperatures of Loads Leaving Plant Compared on a Percentage Basis. Based on Observations on 7 Projects. Mixtures for Base and Leveling Course Observed 172 Days and Mixtures for Surface Course Observed 152 Days.

Figure 10 shows percentage of batches of different temperatures as combined for seven projects. Temperature observations were made on both base and surface mixes at 7 plants on 324 days and in only 55.8 percent of the cases were the temperatures within the specified limits. Extreme ranges of temperature exceeded 100°. Failure to meet the specification for temperature on base and leveling course was most often due to low temperature but in the case of surface course it was most often due to excessive temperature.

Hot materials are transported from the dryer to the screens by a bucket elevator. It is important that both the elevator and screens be housed and insulated to prevent a waste of heat and unsatisfactory results in laying the surface.

SCREENS AND BINS SHOULD BE OF ADEQUATE CAPACITY

In designing a plant for a given capacity it is readily possible to determine the amount of material to be handled by each size of screen. However, the output of a screen depends on a number of variables and designs are based on empiric formulas. The observations which have been made indicate that a margin of production should be provided to care for uncertainties of operation. Troubles arising from inadequate capacity cannot be overcome by overloading screens, increasing the speed of revolving screens beyond a certain limit, or using an excessive pitch. Such measures invariably result in inaccurate screening and should be prohibited by inspectors.

A Modern Plant with Housed Elevator for Hot Materials. A Large Truck Is Loading From the Storage Box.

At several plants material coming from the dryer was dumped first on a fixed, sloping screen (scalping screen) with openings which passed all acceptable sizes and which was arranged to by-pass all oversize material and thus avoid burdening the other screens. At some plants the material coming from the dryer or scalping screen was divided equally between two rotary screens of identical characteristics. Single screens varied from 18 to 24 feet in length where 4 sizes of aggregate were required. The speed of screens varied from 6.3 to 10.3 revolutions per minute and averaged approximately 8 revolutions per minute. Diameters ranged from 5 to 6 feet and the pitch from $\frac{3}{4}$ to $1\frac{1}{4}$ inches per foot.

In general, a single screen 24 feet in length, 6 feet in diameter, with a pitch of $\frac{3}{4}$ inch to the foot, and revolved 8 times per minute should produce 1,200 tons per 8-hour day.

Screened material falls directly in storage bins and these should be large enough to offset irregularities in supply and demand. The bins should be equipped with openings for discharging material, should the supply of a given size become excessive, and also for the removal of cold aggregate. The required bin capacity is closely linked with the accuracy with which the sizes of aggregate are fed to the cold-aggregate elevator. Mistakes in proportioning material in stockpiles soon become evident as trouble with bin supply.

FEW DELAYS RESULT FROM BATCHER OPERATION

In all cases the operation of withdrawing materials from bins in the proper amount for a batch, as determined by weight, was accomplished well within the time required for mixing the previous batch. On some jobs the clogging of filler dust in chutes leading from the bin occasioned delay. Well-designed plants now have screw conveyors for supplying filler if it is used.

STUDY OF PUG MILL OPERATION INDICATES NEED FOR IMPROVEMENTS

Discharge of material from the weighing box to the pug mill was done in a single operation at nearly all plants. In a few cases this practice coupled with large batches and a poorly designed pug mill resulted in the segregation of aggregate in the mix. As a corrective measure it was required in such cases that half a batch be weighed and dumped at a time. This requirement added considerably to the charging time and mixing cycle. The average charging rate on all projects was 263 pounds of material per second and the half-batch charging method lowered this rate to 127 pounds per second. On jobs using a large batch with a single charge the rate was 520 pounds per second. Such a charging rate allows ample time for the accurate weighing of sizes during almost a complete mixing cycle. A single charge is desirable to permit a short period of premixing of the entire dry batch before the asphalt is added.

The mixer is the key unit in the plant set-up. Figure 11 is a sketch of a typical twin-shaft pug mill mixer. The two shafts shown are of heavy steel and each mounts four groups of paddles set at 90° intervals. The faces of the paddles are set at 45° to the plane of rotation. The two shafts rotate at equal speeds so as to force the material inward. The paddles, when in a horizontal position, mesh as shown in the drawing.

Some of the faults of mixers observed in the study are as follows:

1. Dimension A (fig. 11) too large with respect to dimension C resulting in poor end-to-end distribution of material and confining mixing action primarily to planes of rotation.
2. Facing of paddles arranged in a haphazard manner so as to set up uninterrupted paths of flow rather than intercepting paths of flow to cause intermingling.
3. Dimensions D and E too small to permit rotation of paddles at speeds which have been found desirable for good mixing without forcing material over the sides of the box.
4. Dimensions G and H of the discharge opening so small and the discharge rate so low that the paddles are adjusted to aid in discharge rather than set as a result of consideration of mixing requirements only.
5. Speed of revolution too low to impart the necessary violence to the mixing action.
6. Net volume of pug mill reduced too much by the volume of shafts, arms, and paddles.

A satisfactory mixer is one which distributes each size of aggregate and the asphalt uniformly throughout the mix. A better distribution of asphalt might be accomplished by changes in the method of introducing the asphalt in the mix. Studies indicate that where the asphalt is introduced at a single point it should be admitted gradually. The greater the dispersion of the flow the greater the speed of flow which can be permitted and still obtain uniform coating of aggregate.

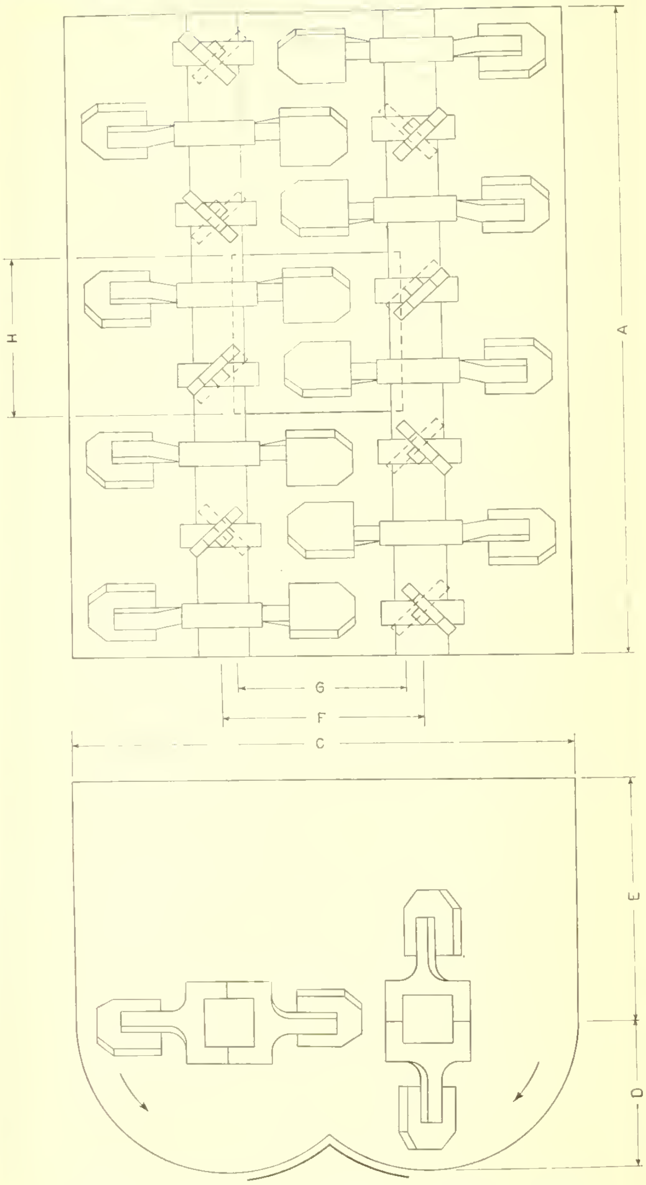


Figure 11.—Typical Twin-Shaft Pugmill Mixer.

Chutes with diverging channels have been used to spread the asphalt over a large area of aggregate. It is believed that improved results might be obtained by forcing the asphalt through pipes leading to a number of points in the mixing box. A piston could be arranged to supply the pressure with the piston adjusted so as to measure the correct amount of asphalt for a batch.

In general, the time required for asphalt distribution is greater than that required for aggregate distribution. It seems possible that practical methods of accelerating asphalt distribution can be developed and this should permit a reduced mixing cycle and increased production.

Wide variations in mixing time were found on practically all of the projects studied. Figure 12 shows the results of the timing of over 280,000 mixing cycles. The observations have been grouped at 5-second intervals and the number of observations in each group plotted as a percentage of the total number of observations in the group. On a typical project in an Eastern State more than 70 percent of the batches were mixed either more or less than the specified time of 45 seconds.

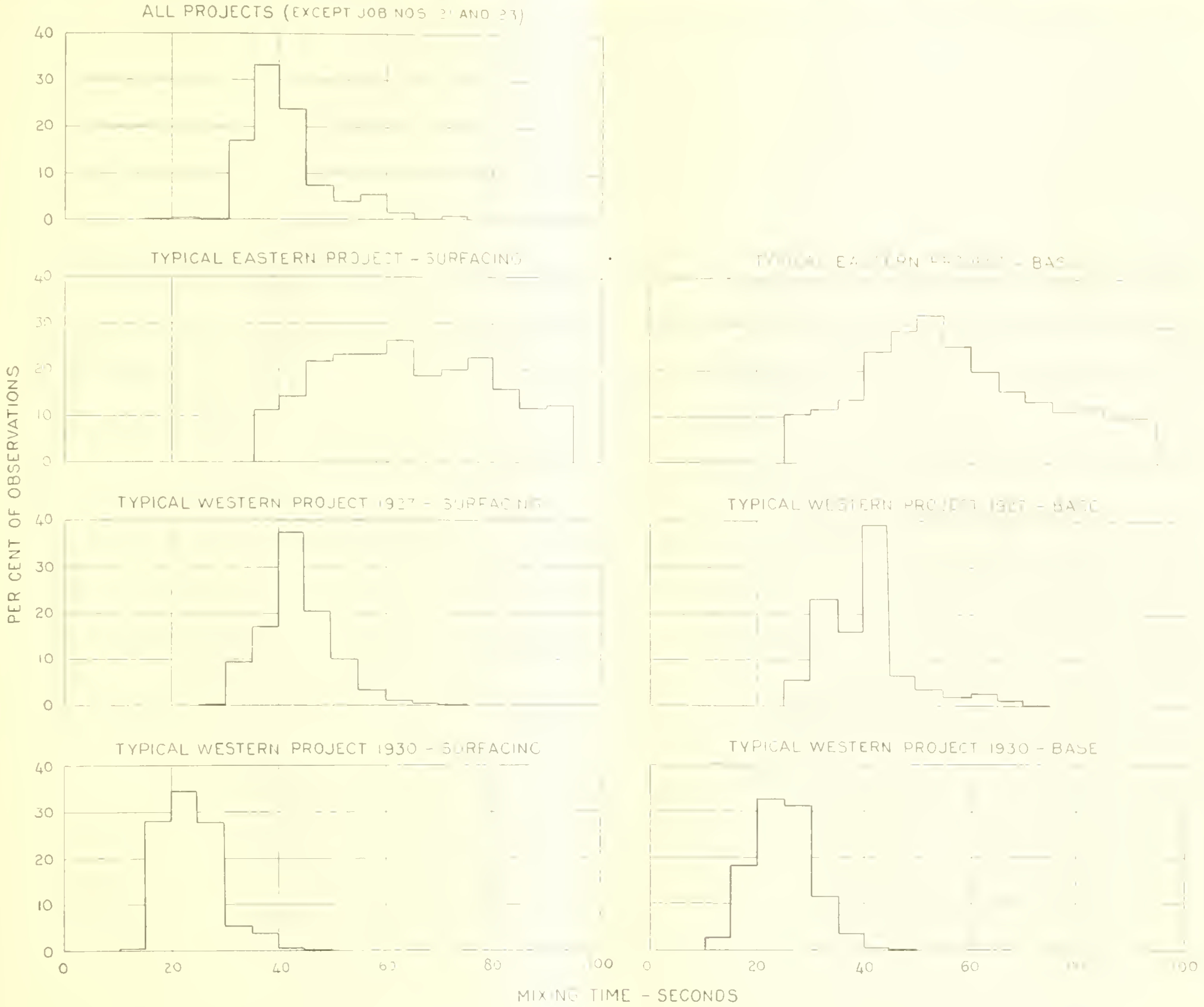


Figure 12.—Mixing Times Grouped at 5-Second Intervals and Plotted on a Percentage Basis.

The typical western project shows a somewhat closer adherence to the 45-second mixing time.

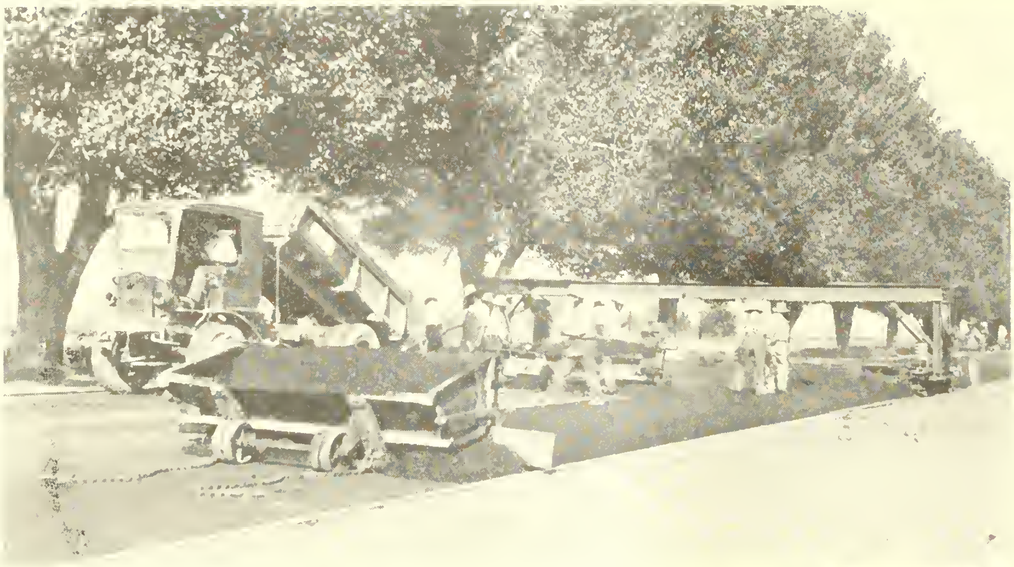
The wide variation in the mixing time found on practically all projects indicates the need for a timing device to control the mixing period. There is also need for research to determine the efficiency of different arrangements of mixers and the mixing time required under any set of conditions.

It has been definitely demonstrated that marked improvements in efficiency of mixing are possible. Representatives of the Bureau of Public Roads cooperated with an asphalt plant manufacturer and a contractor to develop a pug mill of improved design. The ordinary design was altered by decreasing the length of mill and increasing the width and depth. The net volume was increased by reducing the size of paddle and shaft connections. These changes permitted a higher speed of paddle rotation. This machine made possible the lowest mixing cycle yet observed and a record breaking production with full adherence to specifications. A consistent charging time of 4 seconds was obtained ("split" charging not necessary) as compared with an average of 9.9 seconds on other work. A large discharge opening was used through which a batch could be discharged in 3 or 4 seconds as compared with an average discharge time of 13 seconds. No change was made in actual mixing time. The mixing cycle was 51 seconds as compared with an average of 61 seconds.

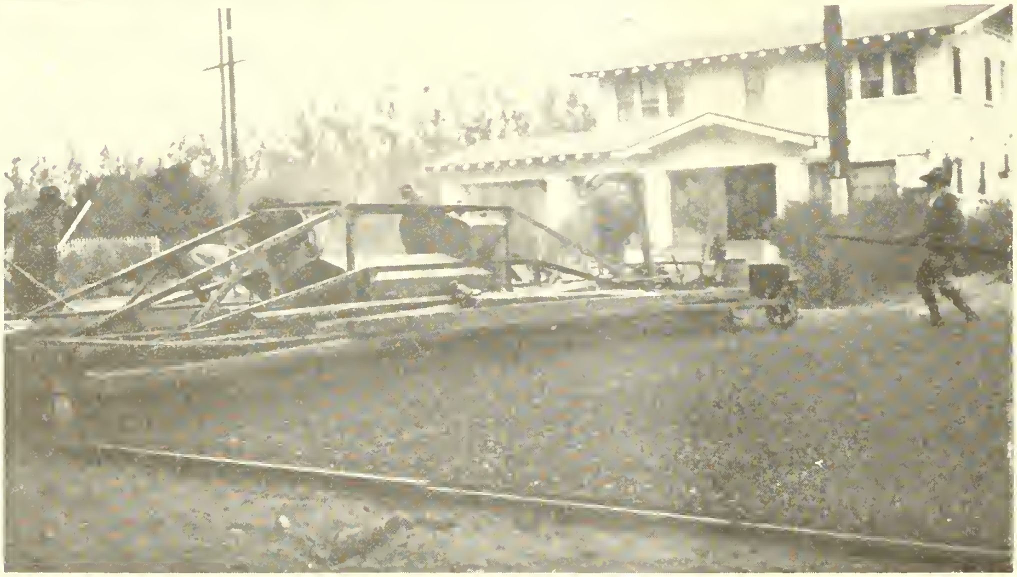
A box for storage of mixed batches, commonly called the "gob box" is essential to allow for temporary differences in mixer production and hauling rate. If the size of batch is less than a truck load a storage box is the only means of avoiding a wait on every truck trip. In such cases delay is wholly unwarranted when so simple and inexpensive a remedy exists.

FINISHING OPERATIONS ON SURFACE COURSE OFTEN LAG BEHIND PLANT PRODUCTION

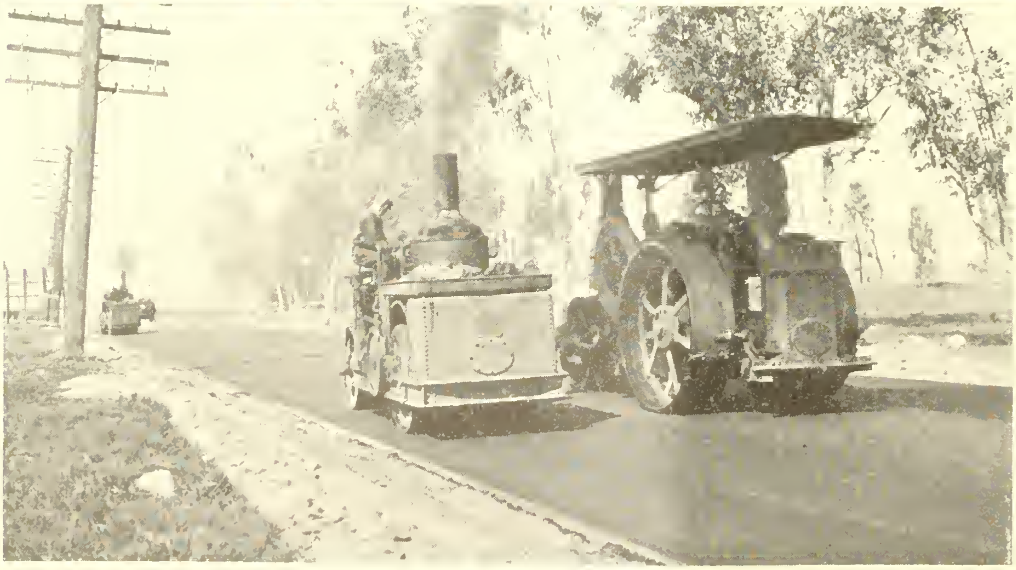
When mixed material is delivered on the road or street it may be handled by one of several methods. The spreading may be entirely by hand or almost entirely by machine methods. Spreader boxes for attachment to trucks have been devised which are very satisfactory in spreading full-width base and surface course and also the narrow strips on widened sections.



Initial Spreading with Spreader Boxes.



Final Spreading with Finishing Machine.



Compaction with Different Types of Rollers.

Steps in Spreading and Rolling.

For upper courses the use of half-width spreader boxes of either the sled or roller type followed by a full width mechanical spreader is particularly recommended.

Mechanical finishers have been used with results that are very satisfactory both in quantity of paving laid and in smoothness of the surface. Such machines have enabled the handling of a larger plant production than could well be handled by hand methods. Finishing machines have been used on standard widths up to 30 feet and have been adapted to narrow strips 9 and 10 feet wide.

It occasionally happens that production is limited by finishing operations rather than plant mixing, and in such cases the finisher is the key unit. For example, on three projects with large capacity plants, a thin surface course required only 1,399 tons per mile or 0.265 ton per lineal foot of road. The plant could supply material for surface course at a rate requiring a finishing speed of 9.46 feet per minute. This speed of finishing could not be consistently maintained and few machines have been observed capable of such a rate. In laying the thicker base course requiring 1,809 tons per mile a speed of 7.32 feet per minute was required. The machines on this job and most of those timed on other jobs were capable of this speed. It would have been possible to adjust the quantities of material for the two courses so as to maintain full plant production with a consistent gross speed of finishing of 8.25 feet per minute. In determining the relative thickness of courses the relation between probable plant production and finishing speed should be considered as a factor affecting cost.

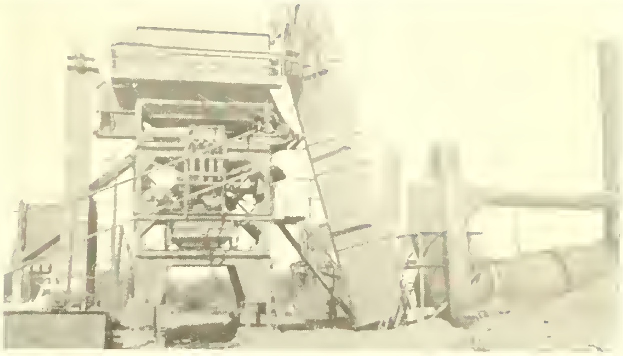
Finishing speeds as high as 12.9 feet per minute during periods of efficient operation were observed, but in only one instance was the finisher capable of maintaining an average speed which matched the maximum production of a large-capacity plant while laying thin surfaces. Reductions in average speed result from insufficient traction and time losses. Tractive losses vary with the number of drive wheels, type and condition of forms or form rails and height of material for some distance ahead of the screed. Time losses result from derailments caused by spreading forms and narrow wheel flanges; faulty spreading of material ahead of the screed requiring backing to fill holes and delays in performing initial spreading.

Tractive losses normally reduce the speed by 8 or 9 percent, but losses of 30 percent have been observed under extreme conditions. Table 10 shows finishing machine speeds observed on several projects.

Very satisfactory finishing machines have been built using a special power unit, special gears, and with four-wheel drive. Such machines have kept pace with a plant production of 187 tons per hour where there was a favorable relation between thickness of base and top course. No great difficulty should be encountered in spreading and finishing operations with a properly designed cross section and mix and properly mixed batches.

STUDY INDICATES NEED FOR MORE EXACT DETERMINATION OF ROLLING REQUIREMENTS

The purposes of rolling are to reduce the voids in the pavement and thereby increase the density and stability and also to produce surface smoothness necessary for riding comfort. In the western States the initial compaction is generally done by longitudinal rolling with three-wheel (macadam type) rollers weighing from 10 to 14 tons and of the gas-engine type. This is followed by longitudinal, transverse, and diagonal rolling with tandem rollers weighing from 6 to 8 tons. Details of typical rollers are shown in table 11.



General View of a Modern Well-Designed Plant Set-Up.

TABLE 10.—*Speed of finishing machines on several projects*

Job no.	Average speed during working time	Average speed with delays and tractive losses eliminated	Reduction in average speed due to delays and tractive losses	
			Base	Surface
	Feet per minute	*Feet per minute*	*Percent*	*Percent*
12	8.70	10.40	16.3	
12	5.20	7.95		34.6
13	3.04	6.70		54.7
16	8.00	9.00	11.1	
18	7.25	9.70	25.3	
19	7.22	11.50		37.2
21	5.00	11.80		57.6
22 [1]	10.32	12.90		20.0
Average	6.84	9.99	17.6	40.8

[1] 4-wheel drive.

As a basis of comparison of amount of rolling on base and surface courses on different projects a "rolling factor" has been derived. This is the product of wheel widths and distance traversed on a given section of pavement divided by the area of the section. Roughly, this factor represents the number of times each unit of area is traversed by a roller wheel. Table 12 shows the successive steps in rolling on two projects.

On job A both the base and the surface course were given nearly twice the amount of rolling as on job B. Assuming a plant production which would require 4 rollers with the rolling factor of job B, substitution of the rolling factor of job A would make 3 additional rollers necessary. These and other observations lead to the conclusion that either some surfaces are insufficiently compacted or there is a waste doing more rolling than is necessary on other surfaces. There is need for a more exact determination of rolling requirements.

TABLE 11.—*Dimensions and weights of typical rollers*

Type	Weight	Wheel weight		Wheel width		Pounds per inch of wheel width	
		Front	Rear	Front	Rear	Front	Rear
	Tons	*Pounds*	*Pounds*	*Inches*	*Inches*		
3-wheel	12.1	6,530	17,620	40.8	40.8	160	430
Do	11.1	6,280	15,880	40.2	43.2	156	367
Tandem	8.6	5,140	12,110	50.4	50.4	102	240
Do	8.5	5,170	11,900	50.4	50.4	103	236

Table 12. *Comparison of amount of rolling on two projects*

Job	Course	Roller type	Weight	Operation	Rolling factor
			Tons		
A	Base	3-wheel	11.1	Initial	5.2
		Tandem	8.5	Final	5.8
	Total				11.0
	Surface	3-wheel	12.1	Initial	12.4
		Do	11.1	Longitudinal	3.5
		Tandem	8.5	Diagonal	6.0
		3-wheel	11.1	Longitudinal	3.1
		Tandem	8.6	Transverse	3.8
	Total				28.8
B	Base	3-wheel	12.0	Initial	3.76
		Tandem	9.2	Final	2.80
	Total				6.56
	Surface	3-wheel	12.0	Initial	7.33
		Tandem	9.0	Longitudinal	4.12
		Do	9.2	Diagonal and transverse	4.28
	Total				15.73

ROLLING DONE AFTER PAVEMENT HAS COOLED THOUGHT TO BE INEFFECTIVE

Time studies reveal that the average roller operates but 70 percent of working time with nonproductive delays as follows:

	Percent
Waiting for material	6
Operator idle	6
Take on fuel	11
Mechanical	6
Miscellaneous	1
Total	30

Wide ranges in roller speed were observed. Speeds of 1.2 to 1.4 miles per hour or 110 to 125 feet per minute appear to be satisfactory and do not result in excessive shoving. In general, higher speeds are used on the base than on the surface course. Typical rates observed were 2,833 square yards per hour on surface and 3,080 on base. The number of rollers required on a project might be estimated as follows:

	Base	Surface
Plant production—lineal feet of road per hour	439	567
Surface laid per hour (20-foot width), square yards	975	1,260
Number of times rolled	4.39	11.13
Area to be rolled per hour, square yards	4,280	14,030
Square yards per hour per roller exclusive of time losses	3,080	2,833
Percentage of working time utilized	51.7	88.3
Square yards per hour per roller allowing for time losses	1,590	2,500
Number of rollers required	3	6

Here again the difference in thickness of base and surface course leads to an increase in the equipment required to keep pace with maximum production. In this case the thicknesses might have been adjusted so that 4 rollers would have been adequate for the project instead of 6.

Observations of volume reduction resulting from rolling were made on selected sections of project A (table 12). Measurements of thickness before and after rolling are based on level readings taken at 1-foot intervals on transverse pavement sections. On given days observations were confined to a particular course and measurements taken on 15 or 20 transverse sections. The results are shown in table 13. Each figure in the table is the average of observations at over 200 points.

These data show that the reduction of volume of the surface course was somewhat less than that of the base course, although the top course received twice as much rolling as the base. The variation from the average was much greater for the surface course than for the base. The base and leveling courses were of identical mix and the average reductions in volume are identical. The surface was composed of a quite different mix and showed different characteristics under rolling. Variations in the temperature of the material as delivered possibly affected the results.

Table 13.—*Reduction in thickness of base and surface courses due to rolling*

Course	Loose thickness	Compacted thickness	Reduction in volume
	Inches	*Inches*	*Percent*
Base:			
First day	3.77	2.77	26.5
Second day	4.96	3.81	23.2
Third day	3.63	2.62	27.8
Average	4.12	3.07	25.6
Leveling:			
First day	2.55	1.75	28.6
Second day	2.42	1.85	23.6
Third day	2.68	2.02	24.6
Average	2.52	1.87	25.6
Surface:			
First day	2.44	2.01	17.6
Second day	2.36	1.70	28.0
Third day	1.78	1.26	29.0
Fourth day	2.69	2.12	21.2
Average	2.32	1.77	23.5

These facts suggested the existence of inherent qualities in the mix affecting the uniformity of volume reduction and led to a series of investigations of the effect of rolling. Batches of various proportions were prepared, spread on the road surface, and subjected to various amounts of rolling with rollers of different weights. The general indication resulting from these tests is that the voids in the mixture are reduced to a minimum value early in the rolling process. On jobs using a light roller on sheet asphalt the point at which there appeared to be no further void reduction or increase in stability was reached after 8 to 12 rollings, depending upon the composition of the mix.

In the rolling tests of asphaltic concrete mixtures, determinations of the density of samples cut from the rolled pavement were made and compared with the theoretical maximum density (no voids) as computed from the quantities and specific gravities of the constituent materials. These data were determined from analysis of samples.

The results of the tests indicate that in general the weight of the roller and the number of rollings above an essential minimum has less effect on the density attained than does the gradation of the aggregate.

It is believed that rolling to produce compaction should be done entirely in a longitudinal direction and that rolling to produce surface smoothness should follow immediately in transverse and longitudinal directions. The entire rolling should be completed before a considerable drop in temperature has taken place and curved or diagonal rolling should be avoided because of the detrimental effect on smoothness. The data shown in the table 14 are typical of the rate at which cooling may take place. The heaviest rollers were used in the first stages of rolling and those of lighter weight were used in the finishing operations which took place about 3 hours after spreading and with the mixture approaching normal temperature. There is considerable reason for believing that the last stages of rolling produced practically no effect on the pavement.

The spreading and rolling operations are conducted so as to produce smoothness and riding comfort. The test for smoothness is usually made with a 10-foot straightedge. However, with cars traveling 40 miles per hour or 59 feet per second a surface which meets the requirement as to smoothness within 10 feet may have variations over greater distances which will produce riding discomfort. The regularity of the surface left by the finishing machine is entirely dependent on the vertical alinement of the side forms and the firmness of their support. It is therefore important that the forms be set conforming to the proper vertical alinement and be supported so as not to deflect under the weight of the finishing machine.

TABLE 14.—*Elapsed time in rolling operations and corresponding drop in temperature of pavement*

Operation	Temperature drop		Elapsed time
	From—	To—	
	° F.	*° F.*	*Minutes*
Spreading	290	275	2
Finishing	275	245	7
First rolling	245	216	15
Second rolling	216	174	41
Third rolling	174	170	43
Fourth rolling	170	161	58
Fifth rolling	161	158	63
Sixth rolling	158	129	143
Seventh rolling	129	128	183

COSTS OF LABOR, EQUIPMENT, AND MATERIALS DERIVED

The preceding discussion has dealt with relative amounts of output under various conditions. It remains to discuss the actual unit costs under these conditions and to determine the actual savings which may be effected by practices which have been advocated.

These costs will be developed under the three main heads of supervision and labor, equipment, and materials. These items are common to all projects and a few miscellaneous items not common to the general run of projects have been omitted from consideration.

The supervision and labor costs are segregated in table 15. The main headings of the table cover the following items:

1. "Supervision and general" includes cost of superintendents, foremen, and labor in connection with supply trucks and other automotive equipment with the exception of trucks hauling mixed material.
2. "Handling material at plant" includes cost of labor in connection with the siding, crane, storage facilities, dryer, and boiler.
3. "Mixing and loading" includes cost of labor in connection with weighing, mixing, elevators, filler storage, and storage of mixed batches.
4. "Hauling" includes cost of labor in connection with hauling mixed batches.
5. "Placing and finishing" includes cost of labor in connection with those operations following delivery of mixed material on the road or street.

Under each of these items there are shown the number of men ordinarily employed, the number of man-hours for the job, the average wage per hour, and the average cost of labor per ton of mixed material.

The hours of labor and payments to labor include those arising during working time and also those resulting from the maintenance of a skeleton organization on full day periods when the plant is not operating.

Table 16 is an analysis of equipment costs under the same general heads as used for labor in table 15. The qualification of these heads as applied to labor apply also to the equipment costs. The costs include such items as fuel, materials (other than for mix), storage, interest, insurance, taxes, repairs and depreciation. The item of depreciation includes that taking place during actual time of operation and also the depreciation occurring during periods when not in operation. An estimate was made for each unit of equipment according to a method which was applied uniformly on all projects.

The cost of materials at the various plants as shown in table 17 is not the true cost but a fictitious value based on the assumption that each plant paid $1.20 per ton for crushed rock, $1 per ton for sand, $16 per ton for asphaltic cement and $6 per ton for filler, all delivered on the job. This procedure was adopted so that the costs would reflect the effect of variations in specifications and construction practices. The above prices are approximately the averages of the prices prevailing on the projects studied. Combined aggregates were delivered on many projects and in such cases the proportions to be classed as coarse aggregate and sand were determined and the assumed costs were applied to these proportions. The average cost of materials per ton of mix is $2.27 of which 33.1 percent is for crushed rock, 16.2 percent for sand, 41.5 percent for asphalt, and 9.2 percent for filler.

The costs of labor, equipment, and materials involved in a ton of mixed material on each project are shown in table 18 which also shows these items on a percentage basis. The cost per ton of paving mixtures ranges from $2.71 to $6.16. The unweighted average cost for all projects is $3.80 per ton and the weighted average is $3.25 per ton, reflecting the lower costs obtained on the larger projects. Figure 13 shows graphically the average costs of each item involved in placing a ton of mixed material in the road surface and also the average cost per ton of material for base and surface course.

AVOIDABLE DELAYS LARGE IN COST

The costs of labor and equipment are almost equal and together they produce approximately 40 percent of the total cost. Elimination of time losses effects a direct saving in labor costs and also tends to reduce equipment costs but does not necessarily reduce the amount of equipment required. It should not be assumed that greater efficiency will adversely affect the employment of labor. There will be a decrease in the hours of labor per mile of road but the decreased costs will permit the construction of a greater total mileage and cause an increase in the production and transportations of materials and machinery.

Table 19 shows the amount and cost of avoidable delay for all projects combined by causes and includes both major and minor delays. Table 20 shows the amount and cost of such delays on each project. This dissipation of potential profit on all projects amounts to nearly 8 percent of the cost of the projects. On one project delays arising from a shortage of hauling equipment resulted in losses equal to the cost of two 5-ton trucks. In another case bin delays caused a loss of $6,000 when half of this amount would have provided facilities which would have completely eliminated this delay. Losses from insufficient dryer capacity have been found large enough to supply a battery of dryers. A contractor purchased a new asphalt pump to replace one causing delay and within a week the savings had offset the cost of the pump. These are typical examples of conditions found on many projects.

TABLE 15.—*Supervision and labor requirements and costs according to type of operation on each of 23 projects*

Project no.	Supervision and general						Handling materials at plant						Mixing and loading					
	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix
1	7	4,123	$3,362	$0.82	0.16	$0.13	6	2,450	$1,517	$0.62	0.10	$0.06	5	2,585	$1,716	$0.66	0.10	$0.07
2	9	6,040	4,695	.78	.21	.16	9	5,019	2,702	.54	.17	.09	6	3,600	2,124	.59	.12	.08
3	8	2,962	1,687	.57	.53	.30	6	1,554	518	.33	.28	.09	5	1,295	544	.42	.23	.10
4	6	2,752	1,479	.54	.26	.11	13	2,641	625	.24	.25	.06	7	1,694	484	.29	.15	.04
5	5	2,920	2,774	.95	.08	.07	9	3,846	2,487	.64	.10	.07	4	1,904	1,214	.64	.05	.03
6	9	5,231	2,603	.49	.59	.29	5	1,351	290	.21	.16	.03	5	1,975	790	.40	.22	.09
7	6	2,768	1,355	.49	.21	.10	7	1,822	439	.24	.14	.03	6	2,004	635	.32	.16	.05
8	2	554	512	.92	.12	.11	5	965	406	.42	.22	.09	3	609	264	.43	.14	.06
9	9	2,838	2,490	.88	.12	.11	7	1,766	920	.52	.08	.04	6	1,824	1,295	.71	.08	.06
10	5	4,237	2,307	.54	.69	.37	5	1,788	487	.27	.29	.08	6	2,382	715	.30	.39	.12
11	5	3,915	2,506	.64	.21	.13	9	5,868	2,386	.41	.32	.13	5	3,260	1,402	.43	.18	.07
12	10	4,198	3,147	.75	.22	.17	8	2,528	1,495	.59	.13	.08	4	1,444	1,079	.75	.08	.06
13	9	1,848	1,382	.75	.77	.58	8	816	369	.45	.34	.15	5	510	292	.57	.21	.12
14	6	1,733	1,462	.84	1.06	.89	12	876	350	.40	.53	.22	5	365	209	.57	.22	13
15	5	1,523	827	.54	.25	.13	8	1,222	351	.30	.20	.06	4	732	229	.31	.12	.04
16	4	3,087	3,192	1.03	.12	13	6	2,250	1,358	.60	.09	.05	4	1,500	1,031	.69	.06	.04
17	6	1,965	1,443	.73	.24	.18	9	2,537	1,315	.52	.31	.16	5	1,575	914	.58	.19	.11
18	11	4,328	5,013	1.16	.11	.12	5	1,448	1,190	.82	.04	.03	5	1,920	1,586	.83	.04	.04
19	11	8,037	6,188	.77	.16	.12	9	4,007	2,260	.56	.08	.05	5	2,565	1,770	.69	.05	.04
20	6	3,346	3,470	1.04	.19	.20	5	1,485	1,007	.68	.09	.06	5	1,485	1,007	.68	.08	.06
21	7	4,568	4,048	.89	.11	.10	16	8,180	4,488	.55	.21	.11	5	2,650	1,834	.69	.07	.05
22	14	3,967	4,728	1.19	.12	.14	8	1,974	1,596	.81	.06	.05	6	1,603	1,250	.78	.05	.04
23	14	4,624	5,255	1.14	.11	.12	8	2,118	1,754	.83	.05	.04	6	1,992	1,483	.78	.04	.03
Total or average	8	81,564	65,925	.81	.17	.14	8	58,511	30,310	.52	.12	.07	5	41,383	23,867	.58	.09	.05

Project no.	Hauling						Placing and finishing						Totals					
	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix
1	10	5,170	$3,877	$0.75	0.20	$0.15	21	9,250	$5,498	$0.59	0.36	$0.21	49	23,578	$15,970	$0.68	0.92	$0.62
2	6	3,600	2,700	.75	.13	.09	13	7,143	4,777	.67	.25	.17	43	25,402	16,998	.67	.88	.59
3	13	3,367	1,347	.40	.60	.24	17	4,403	1,684	.38	.79	.30	49	13,581	5,780	.43	2.43	1.03
4	7	1,694	508	.30	.16	.05	52	10,892	3,534	.32	1.02	.33	85	19,673	6,630	.34	1.84	.62
5	9	4,284	3,213	.75	.11	.08	15	6,921	4,956	.72	.18	.13	42	19,875	14,644	.74	.52	.38
6	5	1,975	593	.30	.23	.07	17	6,715	2,172	.32	.76	.25	41	17,247	6,448	.37	1.96	.73
7	6	2,004	601	.30	.16	.05	26	8,522	2,673	.31	.66	.21	51	17,120	5,703	.33	1.33	.44
8	4	812	406	.50	.18	.09	12	2,436	1,320	.54	.55	.30	26	5,376	2,908	.54	1.21	.65
9	11	3,344	2,508	.75	.14	.11	17	4,987	3,569	.72	.22	.15	50	14,759	10,782	.73	.64	.47
10	7	2,779	834	.30	.45	.14	17	6,749	2,303	.34	1.10	.37	40	17,935	6,646	.37	2.92	1.08
11	9	5,868	2,934	.50	.31	.16	13	8,476	4,434	.52	.45	.24	41	27,387	13,662	.50	1.47	.73
12	6	2,166	1,625	.75	.12	.08	18	5,956	3,974	.67	.32	.21	46	16,292	11,320	.70	.87	.60
13	11	1,122	696	.62	.47	.29	19	1,938	981	.51	.81	.41	52	6,234	3,720	.60	2.60	1.55
14	6	438	219	.50	.27	.13	15	1,095	561	.51	.67	.34	44	4,507	2,801	.62	2.75	1.71
15	11	2,013	604	.30	.32	.10	15	2,745	888	.32	.44	.14	43	8,235	2,899	.35	1.33	.47
16	5	1,875	1,650	.88	.07	.06	14	5,026	3,083	.61	.20	.12	33	13,738	10,314	.75	.54	.40
17	11	3,465	2,079	.60	.43	.26	11	4,410	2,630	.60	.54	.32	45	13,952	8,381	.60	1.71	1.03
18	8	3,072	2,703	.88	.08	.07	22	8,448	6,805	.81	.21	.17	51	19,216	17,297	.90	.48	.43
19	11	5,643	4,232	.75	.12	.09	19	9,137	5,907	.65	.19	.12	55	29,389	20,357	.69	.60	.42
20	6	1,782	1,336	.75	.10	07	13	3,861	2,382	.62	.22	.13	35	11,959	9,202	.77	.68	.52
21	7	3,710	2,783	.75	.09	.07	15	7,950	5,750	.72	.20	.15	50	27,058	18,903	.70	.68	.48
22	8	2,136	1,709	.80	.06	.05	19	4,052	2,942	.73	.12	.08	55	13,732	12,225	.89	.41	.36
23	8	2,536	2,029	.80	.06	.05	19	4,764	3,441	.72	.11	.08	55	15,944	13,962	.88	.37	.32
Total or average	8	64,855	41,186	.63	.14	.09	18	135,876	76,264	.56	.29	.16	47	382,189	237,552	.62	.81	.51

PRODUCTIVE ABILITY OF PLANT CONSPICUOUS IN AFFECTING COSTS

Figure 14 shows graphically the effect of length of mixing cycle, size of batch, efficiency, and productive ability of plant on the hours of labor per ton of mixed material (left column of fig. 14) and also the effect of these factors on the cost of labor and materials per ton of mixed material (right column of fig. 14). In these graphs each plotted point represents the data obtained on a single project and a line has been drawn to represent the trend as nearly as it can be estimated. The effect of length of cycle and efficiency on the amount of labor and cost of labor and equipment is not clearly marked since other factors affect the position of the plotted points. "Tons per batch" show a much clearer relationship and the effect of productive ability on hours of labor and cost stands out significantly.

The graph on the lower right of figure 14 shows the effect of productive ability on cost of labor and equipment combined. The same data with labor and equipment compared separately are shown in figure 15.

CONSIDERATION SHOULD BE GIVEN TO COSTS OF MATERIALS IN DESIGNING MIXES

Up to this point the discussion has dealt mainly with costs of labor and equipment which constituted 40.3 percent of the total cost. Elimination of all avoidable delays would have reduced the cost of labor and equipment by 21.7 percent, making them 34.5 percent of the total cost. Such efficiency is within the reach of the average contractor who will then have 65.5 percent of the total cost involved in materials. Under highly efficient management they may be much higher since on the most efficient project studied labor and equipment costs were 46 percent below the average. It is evident that a discussion of economy in construction of mixed bituminous pavements must take into consideration the relative quantities and costs of the materials.

Use of local materials sometimes offers the opportunity to make savings in their cost and in their transportation. There has been some tendency toward adopting this practice where conditions are favorable.

Table 16.—*Equipment costs on each of 23 projects*

Project number	Supervision and general		Handling material at plant		Mixing and loading		Hauling		Placing and finishing		Total all items	
	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix
1	$1,570	$0.06	$2,475	$0.10	$4,120	$0.17	$5,200	$0.20	$2,330	$0.09	$15,995	$0.62
2	1,600	.05	2,860	.10	6,000	.21	9,370	.33	3,661	.12	23,491	.81
3	218	.01	1,236	.22	1,497	.27	2,231	.40	1,260	.22	6,445	1.15
4	20	.00	1,126	.13	3,829	.36	4,266	.40	1,282	.12	10,823	1.01
5	2,445	.06	2,229	.06	5,202	.11	10,436	.27	3,605	.09	23,917	.62
6	756	.09	159	.02	2,243	.26	3,652	.11	997	.11	7,807	.89
7	145	.01	601	.05	3,297	.25	2,146	.17	1,515	.12	7,734	.60
8	200	.01	523	.12	1,231	.28	1,087	.21	356	.08	3,397	.76
9	384	.02	612	.03	3,370	.11	4,958	.21	1,791	.08	11,145	.48
10	57	.01	1,165	.19	2,610	.43	2,921	.47	2,233	.36	8,986	1.46
11	595	.03	359	.02	3,392	.18	5,777	.31	1,638	.09	11,761	.63
12	535	.03	1,726	.09	3,357	.18	4,031	.21	2,456	.13	12,105	.64
13	292	.12	473	.20	1,185	.50	1,868	.77	831	.35	4,619	1.94
14	157	.10	312	.19	1,165	.70	666	.41	632	.39	2,932	1.79
15	24	.00	728	.12	1,194	.19	2,992	.18	845	.11	5,783	.93
16	530	.02	2,036	.08	5,960	.23	7,145	.28	5,184	.21	20,855	.82
17	14	.00	583	.07	1,294	.16	3,775	.47	1,384	.17	7,050	.87
18	270	.01	1,816	.05	5,773	.11	5,782	.11	4,971	.12	18,612	.46
19	2,732	.06	3,081	.06	10,845	.22	11,202	.23	4,935	.10	32,798	.67
20	360	.02	1,996	.12	4,367	.25	5,478	.31	3,192	.18	15,393	.88
21	407	.01	3,906	.10	7,092	.18	8,274	.21	5,671	.14	25,350	.61
22	1,017	.03	1,450	.04	4,669	.11	4,431	.13	3,140	.09	14,707	.43
23	1,439	.03	1,698	.01	5,471	.13	5,240	.12	3,501	.08	17,349	.40
Weighted average		.03		.07		.19		.21		.12		.65
Unweighted average		.01		.10		.25		.31		.15		.85

Table 17.—*Quantities of materials used and cost computed on basis of an assumed uniform cost for each item on all projects*

Project no.	Rock	Sand	Asphaltic cement	Filler	All materials	Total cost	Total cost per ton of mix
	Tons	*Tons*	*Tons*	*Tons*	*Tons*		
1	16,987	6,779	1,343	643	25,752	$52,510	$2.04
2	18,394	8,467	1,280	690	28,831	55,160	1.91
3	1,936	2,818	470	375	5,599	14,911	2.66
4	1,377	7,798	957	573	10,705	28,201	2.63
5	25,673	9,070	1,810	1,973	38,526	80,676	2.09
6	1,166	6,501	772	368	8,807	22,460	2.55
7	1,658	9,399	1,206	655	12,918	34,615	2.68
8	553	3,138	438	331	4,460	12,795	2.87
9	15,527	5,918	1,063	578	23,086	45,027	1.96
10	737	4,534	548	325	6,144	16,137	2.63
11	3,693	13,914	1,051	0	18,658	35,162	1.88
12	12,221	5,058	920	641	18,840	38,289	2.03
13	828	1,204	201	160	2,393	6,374	2.66
14	567	824	137	110	1,638	4,356	2.66
15	932	4,497	521	248	6,198	15,439	2.49
16	16,632	6,945	1,159	790	25,496	50,008	1.96
17	3,145	3,734	573	696	8,148	20,852	2.56
18	26,985	10,111	2,016	991	40,103	80,695	2.01
19	31,705	13,454	2,441	1,350	48,950	98,656	2.02
20	11,152	4,878	843	681	17,754	35,834	2.04
21	26,804	9,913	1,969	999	39,685	79,576	2.00
22	22,679	8,574	1,592	911	33,756	66,726	1.98
23	29,145	11,243	2,138	1,030	43,556	86,605	1.99

On two recent projects in the Western States four sizes of aggregate were produced from local deposits with excellent results. In each case a semiportable aggregate plant of considerable size was installed and the output was sufficient to care for the maximum production of the mixing plant.

The specification requirements as to composition of the mix produce considerable variation in the costs of material per ton of mix. Table 21 shows the composition of the mix on five typical projects in different sections of the country and the corresponding costs of materials. For purposes of comparison the no. 10 sieve is taken as the dividing line between sand and rock. All percentages are computed on the assumption that the dry weight of aggregate and filler constitute 100 percent and the amount of asphalt is expressed as a percentage of this weight.

Table 18.—*Cost per ton of mix for labor, equipment, and materials (on assumed basis) on each of 23 projects*

Project no.	Cost per ton of mix				Percent of total cost		
	Supervision and labor	Equipment	Materials	Total	Supervision and labor	Equipment	Materials
					Percent	*Percent*	*Percent*
1	$0.62	$0.62	$2.04	$3.28	18.9	18.9	62.2
2	.59	.81	1.91	3.31	17.8	24.5	57.7
3	1.03	1.15	2.66	4.84	21.3	23.8	54.9
4	.62	1.01	2.63	4.26	14.6	23.7	61.7
5	.38	.62	2.09	3.09	12.3	20.1	67.6
6	.73	.89	2.55	4.17	17.5	21.4	61.1
7	.44	.60	2.68	3.72	11.8	16.2	72.0
8	.65	.76	2.87	4.28	15.2	17.8	67.0
9	.47	.48	1.96	2.91	16.1	16.5	67.4
10	1.08	1.46	2.63	5.17	20.9	28.2	50.9
11	.73	.63	1.88	3.24	22.5	19.5	58.0
12	.60	.64	2.03	3.27	18.4	19.6	62.0
13	1.55	1.94	2.66	6.15	25.2	31.6	43.2
14	1.71	1.79	2.66	6.16	27.8	29.0	43.2
15	.47	.93	2.49	3.89	12.1	23.9	64.0
16	.40	.82	1.96	3.18	12.6	25.8	61.6
17	1.03	.87	2.56	4.46	23.1	19.5	57.4
18	.43	.46	2.01	2.90	14.8	15.9	69.3
19	.42	.67	2.02	3.11	13.5	21.6	64.9
20	.52	.88	2.04	3.44	15.1	25.6	59.3
21	.47	.64	2.00	3.11	15.1	20.6	64.3
22	.36	.43	1.98	2.77	13.0	15.5	71.5
23	.32	.40	1.99	2.71	11.8	14.8	73.4
Unweighted average	.68	.85	2.27	3.80	17.9	22.4	59.7
Weighted average	.51	.65	2.09	3.25			

Table 19.—*Cost of avoidable delays on all projects by causes*

Cause of delay	Avoidable major delay	Cost of avoidable major delay	Avoidable minor delay	Cost of avoidable minor delay	Cost of all avoidable delay
	Hours		*Hours*		
Hauling equipment operation	41.0	$1,549	613.5	$37,208	$38,757
Bins empty or overflowing			638.5	38,725	38,725
Handling material at plant	108.6	3,823	83.1	5,058	8,881
Lack of material at plant	149.5	5,263			5,263
Operative at plant			146.2	8,866	8,866
Moving at street	80.3	2,827			2,827
Miscellaneous	73.9	2,602	1.8	109	2,711
Lack of subgrade	75.2	2,647			2,647
Heating material at plant	47.7	1,680			1,680
Late start, management	45.9	1,616			1,616
Handling asphaltic cement and fuel			47.3	2,747	2,747
Finishing			41.4	2,692	2,692
Mechanical at street	31.6	1,113			1,113
Mechanical at plant	7.1	250			250
Total	663.8	23,370	1,573.1	95,405	118,775

TABLE 20.—*Cost of avoidable delays by projects*

Project no.	Cost of labor and equipment per available hour	Avoidable major delay	Cost of avoidable major delay	Cost of labor and equipment per working hour	Avoidable minor delay	Cost of avoidable minor delay	Cost of all avoidable delay
		Hours			*Hours*		
1	$53.20	10.1	$537	$60.80	120.9	$7,351	$7,888
2	55.60	6.5	361	67.00	178.7	11,973	12,334
3	28.00	2.0	56	47.00	32.6	1,532	1,588
4	34.80	13.7	477	70.00	47.5	3,325	3,802
5	66.00	20.6	1,389	78.00	53.8	4,196	5,585
6	17.50	100.5	1,759	31.60	63.4	2,003	3,762
7	25.60	48.0	1,229	36.50	133.0	4,854	6,083
8	22.80	41.8	1,021	26.10	86.8	2,265	3,286
9	68.20	10.7	730	69.70	79.0	5,506	6,236
10	16.30	109.2	1,780	34.90	64.8	2,262	4,042
11	32.50	41.3	1,342	37.00	86.6	3,204	4,546
12	51.10	43.6	2,228	58.60	71.4	4,184	6,412
13	29.10	1.5	44	81.60	23.4	1,909	1,953
14	17.30	2.0	35	78.10	12.5	976	1,011
15	25.90	26.9	697	43.80	61.1	2,676	3,373
16	34.50	49.3	1,701	78.70	93.7	7,374	9,075
17	46.70	6.2	290	48.00	58.2	2,794	3,084
18	90.50	6.6	597	92.10	52.2	4,808	5,405
19	58.30	59.5	3,469	96.90	67.2	6,512	9,981
20	35.70	5.0	179	82.20	26.4	2,170	2,349
21	54.20	43.0	2,331	79.10	112.0	8,859	11,190
22	86.20	10.3	888	97.40	38.2	3,721	4,609
23	92.00	2.5	230	98.00	9.7	951	1,181
Average	35.20	28.9	1,016	60.65	68.1	4,148	5,164

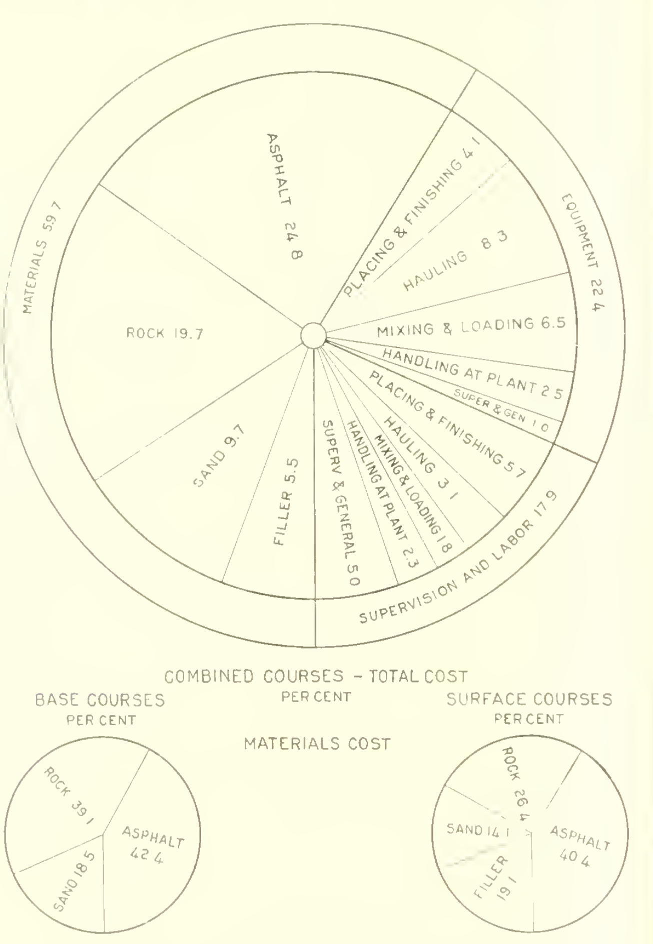


FIGURE 13.—DISTRIBUTION OF AVERAGE COSTS.

Considering the material passing the no. 10 sieve as mortar, table 21 shows that bases have been constructed with a mortar content as low as 23 percent with 5 percent asphalt and as high as 85 percent with 8 percent asphalt. The surface courses range from 33 percent mortar with 5.4 percent asphalt to 100 percent mortar with 10.5 percent asphalt.

Sand-asphalt mixes have been used in regions where rock would have to be transported such distances as to make its use uneconomic. However, there are wide differences in percentages or rock used in base course in regions where rock is readily available. Excellent pavements have been constructed with a high percentage of coarse aggregate in the base and it appears that low percentages of coarse aggregate with the consequent increase in asphalt required are often uneconomic designs.

TABLE 21.—*Composition of mix and costs of materials, equipment, and labor on 5 typical projects*

	Northern bituminous concrete base (4,100 tons) with sheet asphalt surface (3,500 tons)					Western bituminous concrete (225,000 tons in base and 140,127 tons in surface)				
	Rock	Sand	Filler	Asphalt	Cost per ton	Rock	Sand	Filler	Asphalt	Cost per ton
Composition of base and cost of materials	*Percent* 77.1	*Percent* 22.9	*Percent* ------	*Percent* 5.0	$1.87	*Percent* 71.0	*Percent* 28.8	*Percent* 0.2	*Percent* 4.9	$1.85
Composition of surface and cost of materials	------	80.1	19.9	10.5	3.33	67.0	25.3	7.8	5.4	2.26
Composition of combined base and surface and cost of materials	45.1	49.3	9.2	7.6	2.56	69.4	27.5	3.1	5.1	1.99
Cost of—										
Equipment	------	------	------	------	0.87	------	------	------	------	0.60
Labor	------	------	------	------	1.03	------	------	------	------	0.45
Total	------	------	------	------	4.46	------	------	------	------	3.04

	Eastern bituminous concrete (8,400 tons in base and 9,200 tons in surface)					Southeastern sand-asphalt (24,400 tons in base and 20,300 tons in surface)				
	Rock	Sand	Filler	Asphalt	Cost per ton	Rock	Sand	Filler	Asphalt	Cost per ton
Composition of base and cost of materials	*Percent* 21.0	*Percent* 79.0	*Percent* ------	*Percent* 6.0	$1.88	*Percent* 15.0	*Percent* 85.0	*Percent* ------	*Percent* 8.0	$2.14
Composition of surface and cost of materials	21.0	79.0	------	6.0	1.88	13.6	74.1	12.3	12.2	3.20
Composition of combined base and surface and cost of materials	21.0	79.0	------	6.0	1.88	14.3	80.1	5.6	9.9	2.63
Cost of—										
Equipment	------	------	------	------	0.63	------	------	------	------	0.91
Labor	------	------	------	------	0.73	------	------	------	------	0.63
Total	------	------	------	------	3.24	------	------	------	------	4.17

	Southwestern rock asphalt sheet mix for surface (8,800 tons)				
	Rock	Sand	Filler	Asphalt	Cost per ton
Composition of surface and cost of materials	*Percent* 37.8	*Percent* 54.9	*Percent* 7.3	*Percent* 9.2	$2.86
Composition of combined base and surface and cost of materials	37.8	54.9	7.3	9.2	2.86
Cost of—					
Equipment	------	------	------	------	1.46
Labor	------	------	------	------	1.28
Total	------	------	------	------	5.40

RELATION BETWEEN TIME OF MIXING AND UNIFORMITY OF MIX STUDIED

In the studies at various plants attention was given to the relation between time of mixing and the uniformity of the mixed material. A single test for uniformity consisted of taking a sample from each end of the pug mill, analyzing the contents of each sample and comparing the results on a percentage basis. The weight of a sample was approximately 50 times the

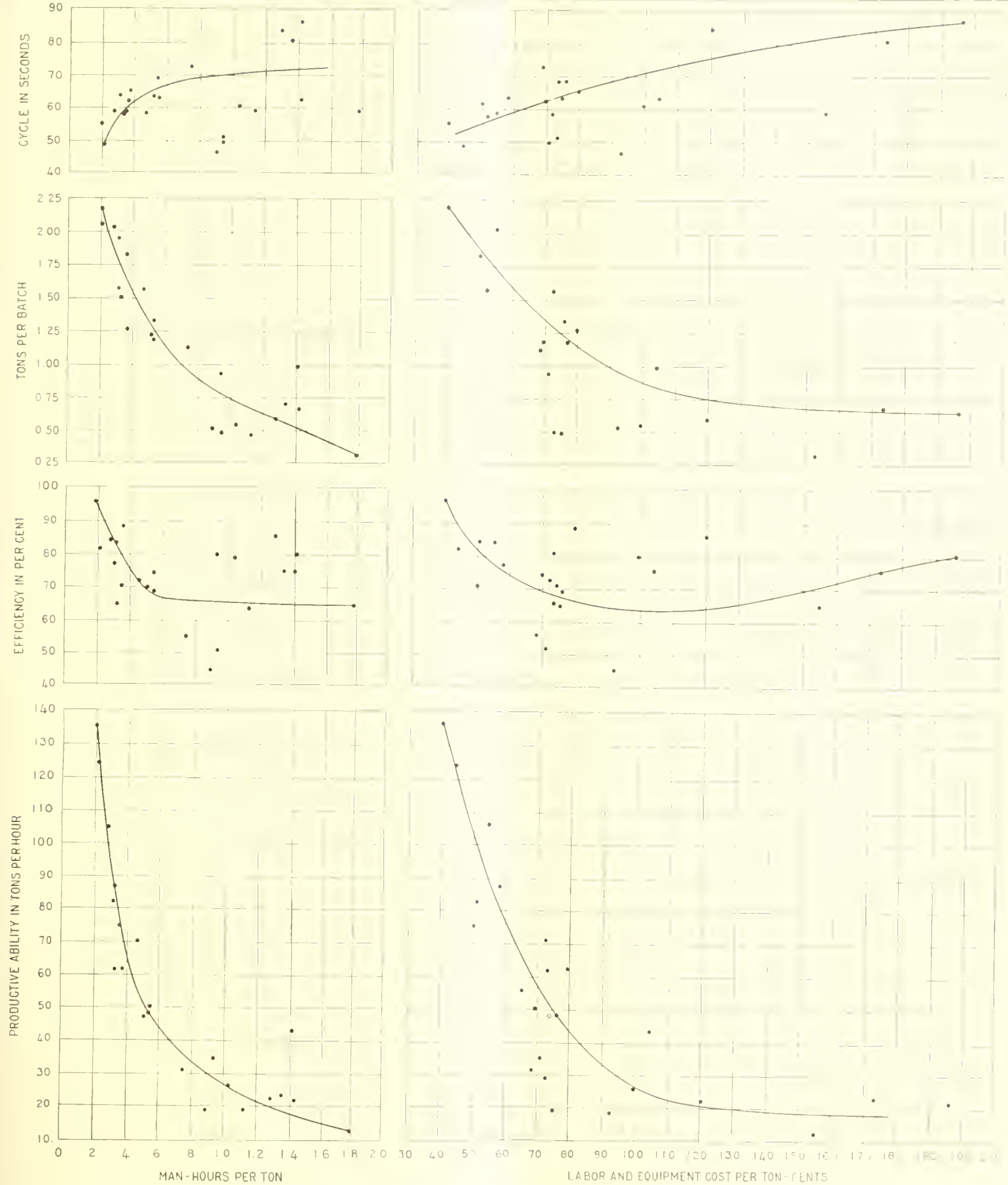


FIGURE 14.—EFFECT OF VARIOUS FACTORS ON HOURS OF LABOR AND COST OF LABOR AND EQUIPMENT.

weight of the largest particle. Asphalt was extracted using commercial benzol as a solvent. Screen analyses were made in an improvised field laboratory.

A series of tests consisted of taking a pair of samples at 10-second intervals through one minute of mixing and then at half-minute intervals up to 3 minutes of mixing. Conclusions are based solely on differences between samples taken at the same instant and no attempt was made to determine the composition of a batch as a whole. Twenty-five series of samples were taken, including different mixes and at five different plants.

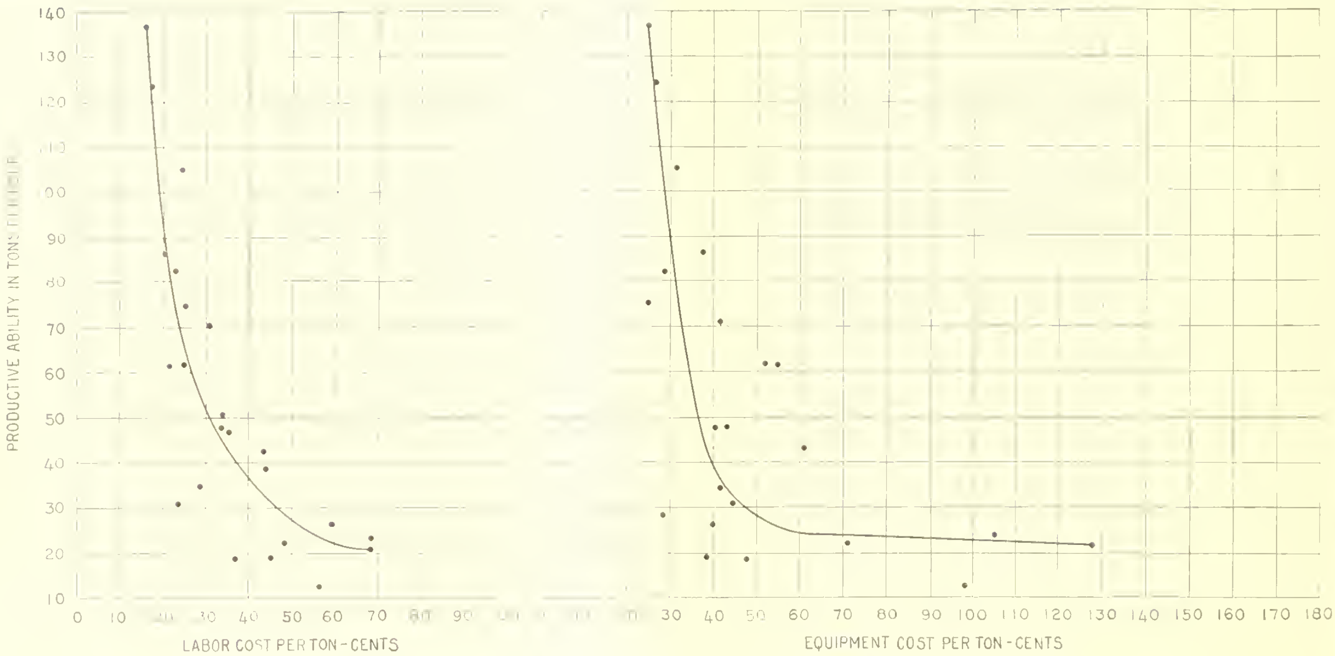


Figure 15.—Effect of Productive Ability on Cost of Labor and Equipment.

Table 22.—*Total percentage differences (see text) between 2 samples taken at same instant for various mixing times and for each series of tests*

Course	Sample series no.	Seconds of mixing: 10	20	30	40	50	60	90	120	150	180
Surface	1	44.6	17.0	22.8	24.0	15.2	9.8	14.0	11.8	23.0	14.0
	2	40.0	25.2	25.2	49.8	14.4	13.2	24.0	10.0	22.6	31.4
	3	31.0	22.0	24.8	9.4	34.4	12.4	2.2	8.6	14.2	13.4
	4	17.0	31.6	30.0	10.0	18.0	23.8	22.0	13.6	16.0	16.2
	5	39.6	21.4	21.8	24.0	33.6	10.4	11.0	24.2	15.2	19.4
	6	77.8	25.0	26.6	48.6	26.2	18.6	42.6	26.0	22.6	13.8
	7	30.2	22.0	23.4	21.8	28.4	20.2	13.4	14.6	13.6	18.6
	8	22.4	19.8	26.4	24.4	22.8	-----	-----	-----	-----	-----
	9	13.2	7.0	22.2	10.4	17.4	-----	-----	-----	-----	-----
	10	45.0	16.3	10.2	22.0	10.4	-----	-----	-----	-----	-----
	11	13.0	6.6	14.2	33.6	33.6	-----	-----	-----	-----	-----
Average	-----	33.98	19.45	22.51	25.27	23.13	15.48	18.46	15.54	18.17	18.11
Levelling	12	52.0	34.4	27.2	17.0	24.2	16.2	28.0	14.6	6.0	17.0
	13	-----	51.8	25.6	23.0	50.2	8.4	6.0	12.4	25.4	6.8
	14	38.0	36.8	24.4	23.8	20.2	21.6	29.2	28.0	30.8	29.8
	15	30.6	33.0	18.6	20.7	36.1	14.8	23.6	12.4	32.8	20.6
	16	43.0	25.6	28.0	37.4	15.0	23.8	24.0	18.4	12.8	22.0
	17	34.2	39.0	30.0	33.2	27.0	31.0	13.8	25.4	12.4	23.2
	18	14.6	33.4	27.8	12.6	25.6	-----	-----	-----	-----	-----
	19	14.8	20.6	16.0	36.4	21.8	-----	-----	-----	-----	-----
	20	27.8	16.8	19.6	25.2	18.2	-----	-----	-----	-----	-----
	21	26.4	18.2	30.4	15.8	24.2	-----	-----	-----	-----	-----
Base	22	44.8	46.2	37.8	34.2	19.2	30.2	11.2	13.2	18.6	19.4
	23	21.6	15.6	13.6	20.2	19.2	-----	-----	-----	-----	-----
	24	36.2	9.4	32.8	48.0	13.0	-----	-----	-----	-----	-----
	25	44.8	16.4	27.8	14.0	24.4	-----	-----	-----	-----	-----
Average, base and leveling		32.97	28.37	25.69	25.82	24.19	20.86	19.40	17.77	19.83	19.83

For each pair of samples the percentage of asphalt and of each size of aggregate were tabulated in adjacent columns. The differences between corresponding percentages were tabulated and then totaled for the pair of samples. These total percentage differences reflect the variation between the two samples. Such totals for each mixing time and for each series of tests are shown in table 22. The average results for all samples show improved mixing with increased mixing time. However, certain of the series show a rise and fall in uniformity such as to suggest the possibility of segregation due to overmixing.

Table 23.—*Variations in pairs of samples in the percentage of material of a given screen or sieve size, averaged for all series, and for each mixing time*

SURFACE COURSE

Seconds of mixing	Screen or sieve size: 1¼ inches	¾ inch	No. 3	No 10	No. 40	No. 80	No. 200	Asphalt cement
10	6.81	9.55	5.34	2.71	4.01	3.32	2.24	2.25
20	4.88	4.70	2.47	1.30	2.17	1.97	1.96	1.75
30	6.28	5.53	4.28	1.70	1.46	1.82	1.44	1.80
40	9.33	4.94	3.40	1.61	2.46	1.55	1.98	1.65
50	7.57	4.74	4.43	2.15	1.41	1.27	1.56	1.59
60	3.24	5.20	1.34	1.50	1.44	1.53	1.23	1.10
90	5.70	3.43	3.54	1.67	1.59	1.19	1.34	.80
120	5.16	3.13	1.87	1.63	1.20	.88	1.67	1.16
150	5.20	6.31	1.92	1.71	.64	.87	1.52	.86
180	6.56	4.70	2.38	1.20	1.04	.59	1.64	.99

LEVELING AND BASE

Seconds of mixing	1¼ inches	¾ inch	No. 3	No 10	No. 40	No. 80	No. 200	Asphalt cement
10	10.74	7.90	6.81	2.10	2.27	2.38	0.77	0.90
20	6.97	9.41	4.79	2.22	2.28	2.05	.65	.91
30	8.74	6.36	5.01	1.23	2.04	2.02	.29	.88
40	8.46	6.41	4.80	1.55	2.41	1.61	.58	.94
50	7.24	5.07	4.54	2.15	2.27	2.29	.63	.87
60	5.06	7.30	4.81	.70	1.34	1.06	.59	.24
90	5.99	3.67	5.23	.93	1.67	1.40	.51	.61
120	5.53	4.14	4.74	.91	1.29	.79	.37	.84
150	5.39	8.17	3.17	.69	1.01	.89	.51	.93
180	7.57	4.33	4.13	.84	1.23	.94	.79	.70

Variations in pairs of samples in the percentage of material of a given screen size or sieve size, averaged for all series, and for each mixing time are shown in table 23.

The data of table 23 when cross totaled cumulatively (excluding asphalt) reflect the relative degree of uniformity of various portions of the mix for the various mixing times. Such totals have been used in plotting figure 16 which also shows the uniformity of the distribution of asphalt. Improvement in uniformity takes place rapidly during the first 60 seconds and at a slower rate thereafter.

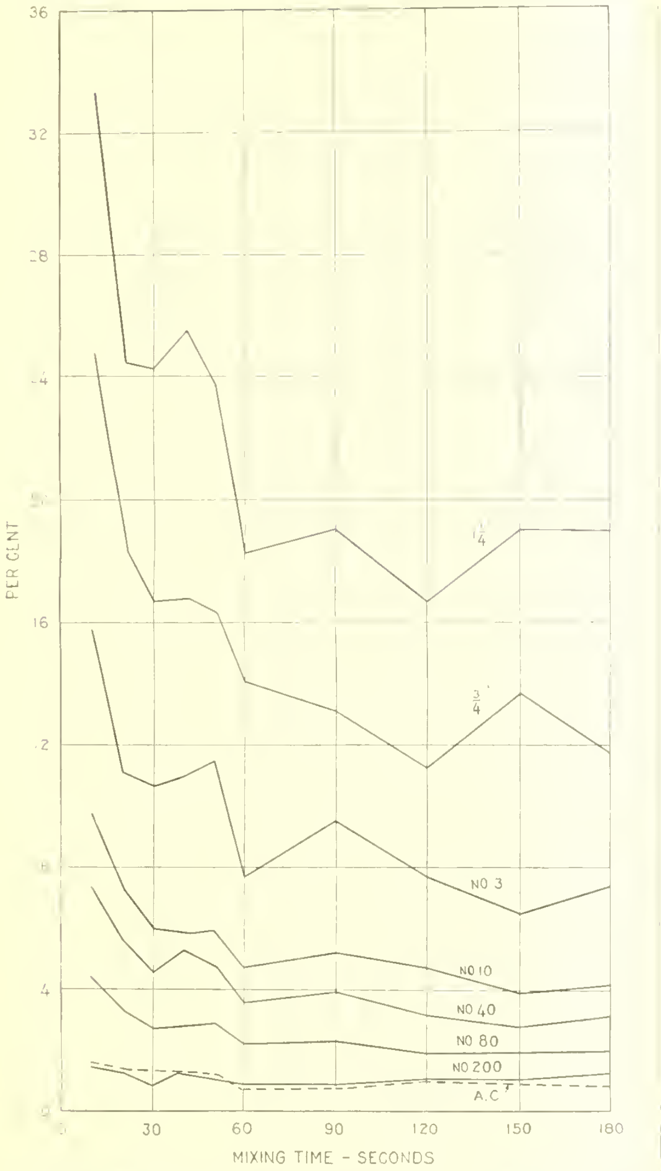


Figure 16.—Percent Difference of Samples from Opposite Ends of Pugmill, Results of All Tests.

ADVANTAGE OF ONE-COURSE PAVEMENT DISCUSSED

In seeking to reduce the cost of asphaltic concrete pavements thought should be given to the design of a mix which will be satisfactory for one-course or monolithic construction. The preceding discussion has demonstrated the increased costs for proportioning, mixing, spreading, and rolling which may result when two unequal courses of different mixes are constructed. The broad range in types of mixes which are being successfully used indicates the possibility of designing satisfactory mixes for one-course pavements. The matter of compacting the necessary thickness in one course does not appear to be a serious obstacle. Table 1 shows the average total thickness of the pavements studied to be slightly over 5 inches. On five of the projects studied single courses in excess of 4 inches were satisfactorily compacted and on one project the depth approached 5 inches.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF MARCH 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 4.185,067					$ 5,281.579.81	$ 2.920.146.40	$ 2,361.433.41	40.7	292.1	$ 287.850.00	24.7	$ 977,070.60
Arizona	3.804.731	$ 497.522.54	$ 497.522.54		33.0	3.150.514.11	2,639.237.56		45.0	219.9	239.779.49	18.0	428.191.41
Arkansas	3.374.167	75.315.69	40.650.69	$ 34.665.00	2.3	1.876.452.07	1.445.942.71	430.509.36	43.9	86.6	989.523.71	71.8	898.049.89
California	7.803.677	587.454.88	496.864.74		11.3	8.013.425.13	6.004.547.70		36.6	244.9	833.188.92	41.9	469.075.64
Colorado	3.437.265	728.229.51	728.229.51		53.4	1.766.437.55	1.755.857.20		39.7	69.3	653.584.14	15.8	299.594.15
Connecticut	1.404.213					1.536.551.82	1.360.772.88	175.778.94	6.8	30.7	39.685.88	.1	3.754.24
Delaware	909.544	133.532.30	133.532.30			742,815.70	742.815.70		25.8	17.4			33.196.00
Florida	2,615.917	176.839.08	97.261.49	79.577.59	6.4	2.848.267.22	2,141.960.60	705.696.52	47.2	102.6	220.909.03	7.0	155.785.88
Georgia	5.045.592	231.655.40	231.655.40		9.8	2,411,144.77	2,411,144.77		41.9	152.7	570.032.06	45.9	1.832.759.77
Idaho	2,166,858	307.083.11	303.761.80		36.1	1.413.185.82	1.401.763.97		45.9	100.4	225.638.63	24.3	235.693.60
Illinois	4.431.348					1.153.986.41	1.153.986.41		21.1	25.3	1.794.460.74	22.1	1.482.900.85
Indiana	4,717,786					2.017.394.80	2.017.394.80		34.4	67.6	1.939.516.14	51.2	760.875.06
Iowa	5.027.830	722,781.94	721.500.00		31.6	4.229,352.32	3.985.230.00		31.1	222.1	263.250.00	15.3	57.850.00
Kansas	5.044.802	538,216.87	538,216.87		100.9	4,112.604.26	4,019.333.22		41.0	282.6	478.187.90	14.1	9.064.01
Kentucky	3.608.332	145,472.40	145.472.40		12.0	2.019.552.67	2.019.552.67		36.1	150.1	1.119.514.20	82.4	323.792.73
Louisiana	2.914,295	38.528.74	38,528.74		1.1	2,459.604.13	1.952.953.13		23.4	59.4	667.484.82	17.0	255.328.31
Maine	1.617.560					1,167.849.93	1.132.282.98		36.9	35.5	242.775.60	8.5	242.501.42
Maryland	1.782.263					801,143.78	791.495.03		10.7	14.8			990.767.97
Massachusetts	1.101.716	153.936.88	83.952.64	69,984.24	4.2	1.160,630.24	844.970.60	315.659.64	20.2	32.9	76.952.29	.7	95.840.47
Michigan	5.094.491	63.000.00	63.000.00		1.8	2.954,300.00	2.954,300.00		28.8	153.7	2.066.516.00	77.6	10.675.00
Minnesota	5.115.153	1.326,915.25	1.326.915.25		320.0	2.023.510.96	2.023,510.96		43.1	283.8	479.862.12	89.2	1.284,864.67
Mississippi	3.489.337	155,273.60	85.400.49	69.873.11	6.6	3.456.288.03	1.864.989.24	1.552,666.85	18.9	185.6	743.186.58	64.0	795.760.69
Missouri	5.237,532	434,210.86	313.743.92		26.3	3.528.655.67	3,510.383.45	50.048.60	37.2	129.6	807.776.07	27.7	605.628.56
Montana	4.463.849	516.749.40	516.749.40		51.5	3.836.697.68	3.430.212.16	326.485.52	35.6	275.0	351.272.88	19.7	165.614.56
Nebraska	3.914.481	380.431.98	255.420.54		144.8	4.003.829.48	3.117.540.42	108.538.00	45.3	181.4	368.365.57	52.1	173.154.47
Nevada	2.909.387	272.235.60	272.235.60		60.2	1.739.088.95	1.739.088.95		42.3	144.8	812.650.99	54.5	85.411.46
New Hampshire	725.739					573.516.95	567.831.95		30.6	9.8	68.469.25	1.0	89.437.80
New Jersey	3,065.137	12.742.75	12.742.75		.2	1.921.643.33	1.914.689.53		7.2	23.7	819.081.25	10.9	318.623.47
New Mexico	2.896.467	1.314,311.91	1.314.311.91		150.6	1.627.684.20	1.491.324.72	102.921.33	10.7	126.7	44.621.19	1.7	46,209.18
New York	10,182.526	117,100.00	117.100.00		3.8	10,765,060.68	9.514.585.68	358.000.00	23.3	224.5	214.428.00	9.4	336.412.32
North Carolina	4.761.147	572.881.72	326.298.27	246,583.45	44.0	2.038,136.42	1.732.712.15	305.424.27	30.9	248.4	1.479.976.39	248.5	1.222.160.19
North Dakota	2.902.224	510.757.38	510.753.87		265.8	864.806.47	864.806.47		17.1	221.4	1.337.731.83	428.9	188.931.83
Ohio	7,277,758	293.134.35	292.290.00		5.9	6,193,130.00	6,010,380.00		33.6	161.1	665.396.00	17.3	309.692.00
Oklahoma	4.608.399	228.526.20	228.417.12		15.9	3.536.333.90	3.536.333.90		45.9	232.7	469.867.08	49.1	373.780.90
Oregon	3.053.448	350.457.26	322.563.76		40.4	2.646,150.29	2,406.493.59	58.505.67	34.5	133.9	222.423.08	8.3	101.967.57
Pennsylvania	6.691.194	12.791.10	12,791.10		.2	4,747,625.05	4.737,013.20		13.6	111.8	1.008.173.70	11.3	933.216.00
Rhode Island	999.354	18.144.13	18.144.13		.5	969.153.21	969.153.21		27.4	20.0	10.468.37		1.588.29
South Carolina	2.729,583	4,168.89	4.168.89			2.000,712.21	1.997.982.59	2.729.62	37.3	184.1	91.205.37	5.2	636.226.15
South Dakota	3.005.739	625.764.57	619.848.08	5.916.49	111.6	1.385.345.41	1.353.321.12	32.024.29	29.8	220.4	621.056 85	100.5	411.512.95
Tennessee	4.246.309	190.117.74	104.645.13	85.472.61	5.8	3.295.717.47	2.805.172.70	490.544.77	29.1	116.8	1,080.392.51	60.7	256,098.66
Texas	12,122.012	1.125.876.08	834.168.39		256.3	8.194.186.45	7.361.257.55		35.3	578.3	1.712.385.24	157.7	2.214.200.82
Utah	2.374.205	854.854.43	854.854.43		101.6	1.203.715.06	1.203.320.16		35.2	87.8	99.127.09	3.9	216.903.32
Vermont	928.184	47.983.81	47.983.81		6.1	735.351.85	707.198.60		36.3	34.7	41.604.99	.7	131.396.60
Virginia	3.708.379	190.180.06	172.607.08	17.572.98	11.1	2.431.083.30	2.430.670.99	412.31	30.1	78.9	1.041.215.55	43.1	63.885.38
Washington	3.057.934	212,292.13	212,271.76		14.1	2,269.656.45	2.266.299.63	3.356.82	33.0	76.8	279.529.44	9.1	299.833.17
West Virginia	2,013.405	194,881.82	194,881.82		6.4	1.545.942.71	1.539.942.71		37.1	63.6	198,870.69	2.2	79.709.78
Wisconsin	4,862.441	298.477.25	288.174.42	1.190.00	15.7	2.596.412.90	2.574.313.37	21.500.00	37.9	99.7	1.165.779.17	79.0	834,174.04
Wyoming	2.250.663	912.725.90	797.131.00	78.000.00	163.8	1,332.768.88	1.207.700.00		12.8	279.9	77.182.61	11.7	168.649.39
District of Columbia													
Hawaii	1.683.956	26,001.46	12.994.33	12.994.32	.9	1.417.975.35	1.186.148.24	181.827.36	19.6	28.6	218.720.78	3.3	266,092.65
TOTALS	185.363.396	15.599.556.97	14.189.756.37	701.829.79	2.134.0	134.296.971.85	119.760.065.57	7.584.063.28	32.3	6.926.4	29.239.670.19	2.109.1	22.173.903.87

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF MARCH 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 2,092,533	$ 29,479.63	$ 29,479.63		0.8	$ 333,928.98	$ 333,928.98		37.7	9.6	$ 564,330.82	19.3	$ 1,164,793.57
Arizona	781,794	22,538.90	22,538.90		.7	176,373.73	174,937.85		13.1	4.5	42,811.39	1.8	541,510.86
Arkansas	1,687,084	17,506.70	15,826.70	$ 1,680.00	.3	572,028.98	501,813.77	$ 70,215.21	41.1	15.3	351,702.85	13.2	817,740.68
California	3,901,839	311,486.74	279,811.54		7.5	2,293,433.76	2,059,163.96		22.0	26.3	907,013.20	10.9	655,850.30
Colorado	1,718,633	170,834.51	170,834.51		4.1	587,891.32	587,891.32		17.9	10.4	521,226.86	12.4	438,680.31
Connecticut	802,407	52,696.86	52,696.86		.5	430,230.83	430,230.83		30.9	6.9	314,554.72	2.8	4,924.59
Delaware	454,772	75,309.50	75,309.50		.8	149,600.00	149,600.00		5.3	1.1	50,710.00	.8	179,152.50
Florida	1,307,959	39,165.31	21,653.41	17,511.90	.2	1,090,654.13	870,400.82	220,253.31	28.7	11.7	415,904.77	5.5	
Georgia	2,724,620	42,177.96	42,177.96		1.9	555,745.71	555,745.71		41.4	20.8	401,909.10	17.6	1,724,787.23
Idaho	1,197,829	22,257.32	22,049.37		1.7	390,958.61	386,923.81		22.2	6.8	125,969.87	5.8	662,885.95
Illinois	6,877,199	58,782.38	58,782.38		.8	3,993,623.20	3,993,623.20		13.4	42.7	2,715,562.10	26.4	109,231.32
Indiana	4,318,165	24,698.54	24,698.54		.4	24,810.85	24,810.85		64.5	.7	2,672,231.73	52.9	2,096,423.88
Iowa	2,815,585	244,176.37	242,350.00		8.6	929,855.23	877,645.00		13.6	17.7	634,650.00	18.5	1,060,940.00
Kansas	2,522,401	51,160.15	51,160.15		3.9	2,115,902.73	1,966,094.48		17.6	26.0	505,146.37	7.2	
Kentucky	2,029,687	13,307.85	13,307.85		.2	236,014.61	236,014.61		5.9	4.3	546,527.52	14.8	1,233,837.02
Louisiana	1,457,148	136,863.72	136,863.72		1.7	293,810.51	293,810.51		49.7	9.2	518,138.50	14.3	508,335.27
Maine	909,878	79,296.57	79,296.57		1.6	350,433.41	350,433.41		36.8	8.6	404,607.03	6.6	75,540.99
Maryland	891,132					16,788.76	12,638.76		99.0	.6			878,493.24
Massachusetts	5,007,199	53,896.49	30,896.49	23,000.00	1.5	3,942,858.28	3,928,758.28	14,100.00	13.7	12.7	250,293.28	1.0	797,250.95
Michigan	4,457,679	180,700.00	180,700.00		2.2	1,890,766.00	1,888,616.00		10.1	21.1	866,600.00	12.9	1,521,763.00
Minnesota	3,410,102	553,219.79	553,219.79		35.9	818,509.75	818,509.75		45.7	33.8	609,126.87	16.4	1,429,245.59
Mississippi	1,744,669	67,501.63	63,751.37	3,750.26	2.2	366,991.49	354,820.99	12,170.50	9.9	14.7	371,733.66	13.1	954,362.98
Missouri	4,019,501	64,021.79	61,736.26		1.4	1,349,266.90	1,213,835.93		30.3	20.2	752,786.25	16.2	1,991,142.56
Montana	1,115,962	2,878.39	2,878.39		.2	414,751.32	414,751.32		30.1	11.7	311,702.73	12.2	386,629.56
Nebraska	1,957,240	29,236.64	28,547.35		3.6	1,096,489.00	1,096,489.00		26.4	17.9	752,405.13	12.7	79,798.52
Nevada	500,051	50,304.27	50,304.27		1.2						45,899.24	1.2	403,847.49
New Hampshire	706,640					538,459.54	538,459.54		9.7	12.9	168,180.46	3.6	
New Jersey	3,217,442	90,163.28	90,163.28		1.4	2,030,463.11	2,030,463.11		26.1	13.2	683,985.71	6.6	412,829.90
New Mexico	1,448,234	47,286.70	47,286.70		2.6	454,094.59	454,094.59		40.7	7.8	732,356.41	16.6	214,496.30
New York	8,530,099	130,131.30	129,750.00		2.2	6,478,477.60	6,030,045.00	39,000.00	17.7	49.3	1,404,822.70	9.9	965,431.30
North Carolina	2,380,573	70,938.35	70,938.35		5.2	477,343.92	477,343.92		22.4	17.7	522,055.69	26.6	1,310,235.04
North Dakota	1,451,112	2,153.29	2,153.29		1.0	49,955.24	49,955.24		52.0	6.2	504,199.80	16.0	894,803.67
Ohio	4,335,686	65,638.97	58,083.75		2.0	1,717,269.43	1,589,281.93		20.8	18.7	2,531,834.00	36.6	156,486.32
Oklahoma	2,304,200	30,917.97	30,901.44		1.9	756,212.40	756,212.40		26.6	16.9	1,115,202.51	21.8	401,883.65
Oregon	1,526,724	99,566.50	99,566.50		2.0	685,410.91	671,095.18	14,315.73	10.6	13.4	453,496.34	9.4	302,565.98
Pennsylvania	4,354,988	120,743.33	119,911.49		4.4	1,538,276.00	1,524,328.93		19.9	27.3	1,895,123.26	22.1	1,315,624.32
Rhode Island	499,677					155,048.79	155,048.79		5.2	2.4	196,041.23	2.9	148,586.98
South Carolina	1,364,791	24,919.48	24,919.48		1.7	431,999.17	431,594.16	405.01	17.8	20.3	16,261.22	1.6	892,016.14
South Dakota	1,502,870	50,799.37	50,799.37		3.3	183,622.25	183,622.25		28.3	7.3	385,589.28	14.8	882,859.10
Tennessee	2,123,155	19,992.06	19,992.06		1.1	661,918.74	661,918.74		27.8	9.0	553,285.01	9.0	887,959.19
Texas	6,061,006	263,679.90	228,684.40		14.8	2,455,126.02	2,303,020.87		24.4	64.7	1,322,392.22	24.6	2,206,908.51
Utah	771,826	372,211.41	372,134.41		8.9	214,492.36	212,733.98		41.4	6.0	60,000.00	1.8	126,957.61
Vermont	500,509	3,854.07	3,854.07		.6	298,777.26	297,549.64		23.5	8.2	199,105.29	5.8	
Virginia	1,854,189	69,060.24	59,408.36	9,651.88	2.8	1,222,522.42	1,018,883.11		19.1	11.5	653,134.71	12.8	122,762.82
Washington	1,377,571	212,091.88	207,347.42		5.5	1,611,609.74	1,611,609.74		12.7	25.8	19,460.21	.9	39,153.63
West Virginia	1,342,270	15,323.43	15,323.43		.4	380,702.34	356,356.60		25.0	6.3	614,456.44	10.7	356,133.53
Wisconsin	2,431,220	151,529.60	151,529.60		4.8	644,150.05	644,150.05		41.9	15.3	847,375.57	21.3	788,164.78
Wyoming	1,125,332	53,504.69	53,004.69		1.1	500,617.97	500,615.69		16.8	11.5	306,077.57	4.9	265,634.05
District of Columbia	959,235	295,510.62	295,510.62		2.4	672,000.45	663,650.15		20.3	2.3			74.23
Hawaii													
TOTALS	114,372,417	4,583,514.45	4,442,134.22	55,594.04	154.0	48,580,268.39	46,683,517.75	370,459.76	20.9	729.3	30,837,979.62	596.8	32,408,785.41

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF MARCH 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2,092,533				$ 93,143.79	$ 93,143.79	40.8	5.0	$ 564,197.75	42.2	$ 1,435,191.46	Alabama
Arizona	625,435				412,835.88	400,573.89	34.4	32.2	25,520.12	.8	199,040.99	Arizona
Arkansas	1,687,084	$ 11,141.83	$ 11,141.83	.2	439,188.26	439,188.26	12.8	38.1	283,783.39	48.9	952,970.52	Arkansas
California	3,901,838	122,219.50	85,059.65	1.7	2,487,099.97	2,071,106.89	22.6	125.1	243,556.40	17.8	1,502,115.06	California
Colorado	1,718,632	90,000.00	90,000.00	19.3	1,004,759.98	1,004,759.98	57.7	132.8	269,062.39	17.7	354,809.63	Colorado
Connecticut	659,120				664,915.58	659,120.00	3.5	14.5				Connecticut
Delaware	454,772				161,554.00	161,554.00		1.8	21,360.00	7.3	271,858.00	Delaware
Florida	1,307,958	72,057.40	72,057.40	8.5	1,144,714.00	1,144,714.00	42.0	59.9	21,345.28	.1	69,841.32	Florida
Georgia	2,320,973				453,343.74	453,343.74	32.9	27.7	462,810.30	36.8	1,404,818.96	Georgia
Idaho	1,121,562	67,404.64	63,302.38	7.0	889,511.02	841,142.00	56.1	117.7	64,000.00	7.4	153,117.62	Idaho
Illinois	6,262,223	78,787.21	78,787.21	19.3	2,779,413.23	2,779,413.23	13.7	182.3	2,121,892.27	110.7	1,282,130.29	Illinois
Indiana	501,892				189,508.90	189,508.90	17.9	42.4	244,793.75	22.1	67,589.35	Indiana
Iowa	2,212,245	85,897.35	83,000.00	27.3	725,443.41	690,700.00	32.4	71.5	589,100.00	69.7	849,445.00	Iowa
Kansas	2,522,401	11,865.47	11,865.47	3.7	1,810,190.29	1,810,190.29	16.5	133.7	689,713.59	26.8	10,631.65	Kansas
Kentucky	1,879,340	52,828.05	52,828.05	16.1	1,480,016.42	1,480,016.42	27.6	172.2	321,679.44	30.9	24,816.09	Kentucky
Louisiana	1,457,148	61,627.65	61,627.65	2.2	468,932.69	468,932.69	4.9	21.6	460,748.64	21.3	465,839.02	Louisiana
Maine	842,479	489,078.07	488,198.56	54.5	403,386.85	337,221.58	86.0	36.6	8,989.70	.2	8,069.16	Maine
Maryland	891,132				240,544.07	240,544.07	21.2	18.6	497,081.30	34.6	153,506.63	Maryland
Massachusetts	488,185				469,741.41	469,741.41	37.0	15.2			18,443.59	Massachusetts
Michigan	3,184,057	88,500.00	88,500.00	7.4	1,880,350.00	1,880,350.00	10.2	146.1	889,350.00	71.1	325,857.00	Michigan
Minnesota	2,131,314	45,666.23	45,666.23	34.6	1,438,466.76	1,358,035.76	37.6	200.0	313,308.15	32.7	414,303.86	Minnesota
Mississippi	1,744,669				459,999.99	459,999.99	47.6	54.6	282,216.49	28.3	1,002,452.52	Mississippi
Missouri	2,923,273	18,488.65	18,488.65	4.0	2,550,256.61	2,550,256.61	41.8	458.3	162,026.53	23.9	192,501.21	Missouri
Montana	1,859,937	105,097.67	105,097.67	16.0	1,016,863.81	1,016,863.81	9.7	109.3	637,706.80	85.0	100,268.72	Montana
Nebraska	1,957,240				1,823,129.74	1,821,267.42	30.7	253.0	134,179.61	30.9	1,792.97	Nebraska
Nevada	1,136,479	24,880.52	24,880.52	.4	965,151.01	965,151.01	45.5	96.6			146,447.47	Nevada
New Hampshire	477,460				518,207.67	477,383.82	36.4	25.7			76.18	New Hampshire
New Jersey	63,460				56,550.52	56,550.52	14.1	.5			6,909.48	New Jersey
New Mexico	1,448,234	8,500.00	8,500.00	1.6	951,500.00	951,500.00	58.2	343.5			488,234.00	New Mexico
New York	3,617,476	143,946.51	143,946.51	4.6	3,809,913.19	3,378,488.19	19.9	93.1	85,975.00	1.9	9,066.30	New York
North Carolina	2,380,573	145,298.61	145,298.61	18.4	1,103,591.71	1,103,591.71	45.6	98.9	106,946.10	15.9	1,024,736.58	North Carolina
North Dakota	1,451,112								106,552.87	18.2	1,344,559.13	North Dakota
Ohio	3,871,148	190,100.00	190,100.00	68.5	2,610,880.00	2,470,244.90	25.9	207.7	1,036,450.00	28.7	174,353.10	Ohio
Oklahoma	2,304,199				285,063.50	285,063.50	4.9	28.8	1,508,329.88	205.3	510,805.62	Oklahoma
Oregon	1,526,724				968,962.59	924,636.75	24.2	30.3	602,087.25	78.2		Oregon
Pennsylvania	7,344,822	39,596.00	39,596.00	4.9	6,387,324.88	6,312,722.68	25.3	590.9	508,432.19	46.6	484,071.13	Pennsylvania
Rhode Island	499,677				226,847.63	226,847.63	2.6	20.9	185,162.59	12.3	87,666.78	Rhode Island
South Carolina	1,364,791				1,174,986.08	1,174,986.08	35.8	133.8			189,804.92	South Carolina
South Dakota	1,502,870	53,493.81	53,493.81	19.9	78,013.63	78,013.63	52.6	27.0	318,183.34	117.4	1,053,179.22	South Dakota
Tennessee	2,123,155				996,285.00	996,285.00	17.9	83.7	199,796.07	13.2	927,073.93	Tennessee
Texas	6,061,006	391,183.38	297,245.50	76.8	5,080,782.70	4,279,989.90	40.7	587.6	715,464.54	98.9	768,306.06	Texas
Utah	1,048,677	218,991.79	216,610.42	45.2	669,084.56	658,411.65	36.3	111.0	68,967.69	5.8	104,687.24	Utah
Vermont	438,880				336,541.00	318,237.70	23.9	29.2	120,642.30	7.3		Vermont
Virginia	1,854,189	73,918.51	65,000.72	32.1	1,401,482.85	1,316,727.79	39.9	172.9	472,460.49	10.8		Virginia
Washington	1,180,362	90,437.72	90,437.72	13.3	897,127.37	887,127.37	21.0	45.6	111,723.58	8.4	91,073.33	Washington
West Virginia	1,118,559				523,473.59	523,473.59	17.6	28.1	495,404.64	31.7	99,680.77	West Virginia
Wisconsin	2,431,220	223,248.44	223,248.44	7.8	1,263,471.40	1,224,036.68	12.3	87.7	706,770.47	54.1	277,164.41	Wisconsin
Wyoming	1,125,332	237,058.12	231,300.00	28.7	556,290.81	546,155.20	27.5	87.2	269,716.19	33.5	78,160.61	Wyoming
District of Columbia	959,234	110,674.64	110,674.64	2.0	748,207.37	748,207.37	20.8	5.1	100,201.99	.6	150.00	District of Columbia
Hawaii	187,106								177,717.69	4.9	9,388.31	Hawaii
TOTALS	94,264,187	3,351,987.77	3,195,953.64	546.0	57,097,049.46	54,725,821.40	28.7	5,406.0	17,205,406.77	1,560.9	19,137,005.19	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

DEPARTMENT BULLETINS

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No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

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No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

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REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF MARCH 31,1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8,370,133	$ 29,479.63	$ 29,479.63		.8	$ 5,708,652.58	$ 3,347,219.17	$ 2,361,433.41	40.4	306.7	$ 1,416,378.57	86.2	$ 3,577,055.63
Arizona	5,211,960	520,061.44	520,061.44		33.7	3,739,723.72	3,215,044.30		41.9	256.6	308,111.00	20.6	1,168,743.26
Arkansas	6,748,335	103,964.22	67,619.22	$ 36,345.00	2.8	2,887,669.31	2,386,944.74	500,724.57	37.6	140.0	1,625,009.95	133.9	2,668,761.09
California	15,607,354	1,021,161.12	861,735.93		20.5	12,793,958.86	10,134,818.55		30.8	396.3	1,983,758.52	70.6	2,627,041.00
Colorado	6,874,530	989,064.02	989,064.02		76.8	3,359,088.85	3,348,508.50		41.3	212.5	1,443,873.39	45.9	1,093,084.09
Connecticut	2,865,740	52,696.86	52,696.86		.5	2,631,698.23	2,450,123.71	175,778.94	10.2	52.1	354,240.60	2.9	8,678.83
Delaware	1,819,088	208,841.80	208,841.80		.8	1,053,969.70	1,053,969.70		19.0	20.3	72,070.00	8.1	484,206.50
Florida	5,231,834	288,061.79	190,972.30	97,089.49	15.1	5,083,635.35	4,157,075.42	925,949.83	41.9	174.2	658,159.08	12.6	225,627.20
Georgia	10,091,185	273,833.36	273,833.36		11.7	3,420,234.22	3,420,234.22		40.6	201.2	1,434,751.46	100.3	4,962,365.96
Idaho	4,486,249	390,745.07	389,113.55		44.8	2,693,655.45	2,629,829.78		45.7	224.9	415,608.50	37.5	1,051,697.17
Illinois	17,570,770	137,569.59	137,569.59		20.1	7,927,022.84	7,927,022.84		14.6	250.3	6,631,915.11	159.2	2,874,262.46
Indiana	10,037,843	24,698.54	24,698.54		.4	2,231,714.55	2,231,714.55		33.3	110.7	4,856,541.62	126.2	2,924,888.29
Iowa	10,055,660	1,052,855.60	1,046,850.00		67.5	5,884,650.96	5,553,575.00		28.5	311.3	1,487,000.00	103.5	1,968,235.00
Kansas	10,089,604	601,242.49	601,242.49		108.5	8,038,697.28	7,795,617.99		29.4	442.3	1,673,047.86	48.1	19,695.66
Kentucky	7,517,359	211,608.30	211,608.30		28.3	3,735,583.70	3,735,583.70		30.8	326.6	1,987,721.16	128.1	1,582,445.84
Louisiana	5,828,591	237,020.11	237,020.11		5.0	3,222,347.33	2,715,696.33		23.1	90.2	1,646,371.96	52.6	1,229,502.60
Maine	3,369,917	568,374.64	567,495.13		56.1	1,921,670.19	1,819,937.97		46.0	80.7	656,372.33	15.3	326,111.57
Maryland	3,564,527					1,058,476.61	1,044,677.86		14.3	34.0	497,081.30	34.6	2,022,767.84
Massachusetts	6,597,100	207,833.37	114,849.13	92,984.24	5.7	5,573,229.93	5,243,470.29	329,759.64	16.8	60.8	327,245.57	1.7	911,535.01
Michigan	12,736,227	332,200.00	332,200.00		11.4	6,725,416.00	6,723,266.00		18.4	320.9	3,822,466.00	161.6	1,858,295.00
Minnesota	10,656,569	1,925,801.27	1,925,801.27		390.5	4,280,487.47	4,200,056.47		41.8	517.6	1,402,297.14	138.3	3,128,414.12
Mississippi	6,978,675	222,775.23	149,151.86	73,623.37	8.8	4,283,279.51	2,679,810.22	1,564,837.35	22.6	254.9	1,397,136.73	105.4	2,752,576.19
Missouri	12,180,306	516,721.30	393,968.83		31.7	7,728,179.18	7,274,475.99	50,048.60	37.7	608.1	1,722,588.85	67.8	2,789,272.33
Montana	7,439,748	624,725.46	624,725.46		67.7	5,268,312.81	4,861,827.29	326,485.52	29.7	396.0	1,300,682.41	116.9	652,512.84
Nebraska	7,828,961	409,668.62	283,967.89		148.4	6,923,448.22	6,035,296.84	108,538.00	37.5	452.3	1,254,950.31	95.7	254,745.96
Nevada	4,545,917	347,420.39	347,420.39		61.8	2,704,239.96	2,704,239.96		43.5	241.4	858,550.23	55.7	635,706.42
New Hampshire	1,909,839					1,630,184.16	1,583,675.31		25.3	48.4	236,649.71	4.6	89,513.98
New Jersey	6,346,039	102,906.03	102,906.03		1.6	4,008,656.96	4,001,703.16		16.9	37.4	1,503,066.96	17.5	738,362.85
New Mexico	5,792,935	1,370,098.61	1,370,098.61		154.8	3,033,278.79	2,896,919.31	102,921.33	31.0	478.0	776,977.60	18.3	748,939.48
New York	22,330,101	391,177.81	390,796.51		10.6	21,053,451.47	18,923,118.87	397,000.00	20.9	366.9	1,705,225.70	21.2	1,310,959.92
North Carolina	9,522,293	789,118.68	542,535.23	246,583.45	67.6	3,619,072.05	3,313,647.78	305,424.27	34.6	365.0	2,108,978.18	291.0	3,557,131.81
North Dakota	5,804,448	512,910.67	512,907.16		266.8	914,761.71	914,761.71		19.0	227.6	1,948,484.50	463.1	2,428,294.63
Ohio	15,434,592	548,873.32	540,473.75		76.4	10,521,279.43	10,069,906.83		29.7	387.5	4,233,680.00	82.6	640,531.42
Oklahoma	9,216,798	259,444.17	259,318.56		17.8	4,577,609.80	4,577,609.80		40.2	278.4	3,093,399.47	276.2	1,286,470.17
Oregon	6,106,896	450,023.76	422,130.26		42.4	4,300,523.79	4,002,225.52	72,821.40	28.1	177.6	1,278,006.67	95.9	404,533.55
Pennsylvania	18,891,004	173,130.43	172,298.59		9.5	12,673,225.93	12,574,064.81		20.2	730.0	3,411,729.15	80.0	2,732,911.45
Rhode Island	1,998,708	18,144.13	18,144.13		.5	1,351,049.63	1,351,049.63		20.7	43.3	391,672.19	15.2	237,842.05
South Carolina	5,459,165	29,088.37	29,088.37		1.7	3,607,697.46	3,604,562.83	3,134.63	34.5	338.2	107,466.59	6.8	1,718,047.21
South Dakota	6,011,479	730,057.75	724,141.26	5,916.49	134.8	1,646,981.29	1,614,957.00	32,024.29	30.7	254.7	1,324,829.47	232.7	2,347,551.27
Tennessee	8,492,619	210,109.80	124,637.19	85,472.61	6.9	4,953,921.21	4,463,376.44	490,544.77	26.4	211.5	1,833,473.59	82.9	2,071,131.78
Texas	24,244,024	1,780,739.36	1,360,098.29		347.9	15,730,095.17	13,944,268.32		35.2	1,230.6	3,750,242.00	281.2	5,139,415.39
Utah	4,194,708	1,446,057.63	1,443,599.26		155.7	2,087,291.98	2,074,465.79		36.2	204.8	228,094.78	11.5	448,548.17
Vermont	1,867,573	51,837.38	51,837.38		6.7	1,370,670.11	1,322,985.94		30.5	72.1	361,352.58	13.8	131,396.60
Virginia	7,416,757	333,158.81	297,016.16	27,224.86	46.0	5,055,088.57	4,766,281.89	412.31	30.5	263.3	2,166,810.75	66.7	186,648.20
Washington	6,115,867	514,821.73	510,056.90		32.9	4,778,393.56	4,765,036.74	3,356.82	23.9	148.2	410,713.23	18.4	430,060.13
West Virginia	4,474,234	210,205.25	210,205.25		6.8	2,450,118.64	2,419,772.90		31.1	98.0	1,308,731.77	44.6	535,524.08
Wisconsin	9,724,381	673,255.29	662,952.46	1,190.00	28.3	4,504,034.35	4,442,500.10	21,500.00	31.4	202.7	2,719,925.21	154.4	1,899,503.23
Wyoming	4,501,327	1,203,288.71	1,081,435.69	78,000.00	193.6	2,389,677.66	2,254,470.39		17.2	378.6	652,976.37	50.1	512,444.05
District of Columbia	1,918,469	406,185.26	406,185.26		4.4	1,420,207.82	1,411,357.52		20.6	7.4	100,201.99	.6	224.23
Hawaii	1,371,062	26,001.46	12,994.33	12,994.32	.9	1,417,975.35	1,186,148.24	131,827.36	19.6	28.6	396,438.47	8.2	275,480.96
TOTALS	394,000,000	23,535,059.19	21,827,844.23	757,423.83	2,834.0	239,974,289.70	221,169,404.72	7,954,523.04	29.0	13,061.7	77,283,056.58	4,266.8	73,719,694.47

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 3 MAY 1934

CONSTRUCTING A CUT WITH A BULLDOZER

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 3 May 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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SOME NEW RELATIONS BEARING ON CONCRETE MIXTURES

BY THE DIVISION OF MANAGEMENT, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by William A. Blanchette, Highway Engineer, Division of Management, United States Bureau of Public Roads

IN INVESTIGATIONS recently conducted at East Point, Ga., the Division of Management of the United States Bureau of Public Roads has studied the effects of variation in the proportions of the solid ingredients of concrete and its water content upon the quality of the resulting mixture as measured by its density and strength. The tests have developed indications of certain relations not heretofore established which it is believed constitute an addition of fundamental importance to the knowledge of the character of concrete mixtures.

Perhaps the most widely accepted generalization concerning the strength of concrete is the water-cement-ratio theory which suggests that the most important factors in determining strength are the relative amounts of water and cement.

To this concept the work of Talbot and Richart has added, with respect to mortars, definite knowledge of the relations existing between the water content and the voids in the cement-sand mixture and the bearing of these relations upon the strength of the mortar. They showed definitely that for any given combination of various amounts and kinds of cement and sand addition of a certain amount of water will produce a mortar of maximum density, and they called this amount the "basic water content." With all other amounts of water, either greater or less than the basic amount, a lesser density was obtained in the resulting mortar.

It was found convenient to express the quantity of water added in terms of the basic quantity as a "relative water content" by means of an index figure. Thus, a mixture containing an amount of water one tenth greater than the determined basic quantity was said to have a relative water content of 1.1.

In the investigations conducted by the Division of Management the method of determining the amount of water required to give maximum density to each particular combination of materials was similar to that of Talbot and Richart except that in this work concrete mixtures were used instead of mortar mixtures.

NEW RELATIONS DEVELOPED

The principal new relations developed are as follows:

1. For a particular combination of sand and cement a relation exists between the amount of coarse aggregate in the mixture and (1) the amounts of water required as the basic and various relative water contents and (2) the corresponding total voids in the mixture. As the coarse aggregate content is uniformly increased, the amount of water required for the basic and each relative water content and the total voids in the concrete corresponding to each, are uniformly decreased.

2. Likewise, for a particular coarse aggregate content, a relation exists between the ratio of the amounts of sand and cement in the mixture and (1) the amounts of water required as the basic and various relative water contents, and (2) the corresponding total voids in the mixture. As the sand-cement ratio is uniformly increased, a uniform change occurs in the amount of water required for the basic and each relative water content and the total voids in the concrete corresponding to each. In these tests, increase in the ratio of sand to cement resulted in an increase in both the amounts of water required for each relative water content and the corresponding total voids in the concrete.

3. For each relative water content, using the same kinds of materials, the slump of every concrete mixture will be the same regardless of the proportions of cement and aggregate used in it.

MECHANICAL METHOD DEVISED FOR MOLDING TEST SPECIMENS

The studies were to involve the molding of concrete specimens with various water contents for density determinations. The densities determined were to be used in drawing concrete-voids curves from which actual water requirements for each particular mixture were to be determined. Specimens for strength tests were also to be made containing the specific amounts of water as indicated by these curves. It was regarded as important that a method be used for consolidating both the density and strength specimens that would be consistent and uniform in its operation in order that the densities in the strength specimens should closely and uniformly approximate the densities of such mixtures as indicated by the concrete-voids curves. It was also desired that the method should be capable of reproducing in the density and strength specimens, a density corresponding closely with the density of concrete produced in pavements by the customary methods of mixing, placing, and finishing.

A mechanical compacting machine was devised and constructed for this purpose. The machine is driven by an electric motor and consists of a rectangular steel table, the drops or impacts of which are actuated by a series of gears and a cam, causing the table to rise and fall freely upon two 3-inch steel cylinders. These cylinders are bored to receive two 1-inch steel pistons which guide the motion of the table. The distance of fall and the rate at which impacts are delivered to the table can be varied, allowing the machine to be operated so as to produce a density in the specimen that tends to duplicate the density of the same concrete mixture as placed in a particular work by a particular method of manipulation.

Figure 1 is a detailed drawing of this machine and illustrations of it are shown in figure 2.

Considerable preliminary work was done to determine the extent to which the machine accomplished the purposes for which it was constructed. Density specimens were molded on the machine by different methods of operation. The concrete-voids curves resulting from these determinations indicated that the density of a concrete mixture could be changed by changing the operation of the machine, and that the machine could be operated in such a manner as to duplicate the density of the same concrete as placed in the work.

Comparisons were made of concrete-voids curves resulting from tests of specimens compacted by the mechanical method and by the standard method of hand

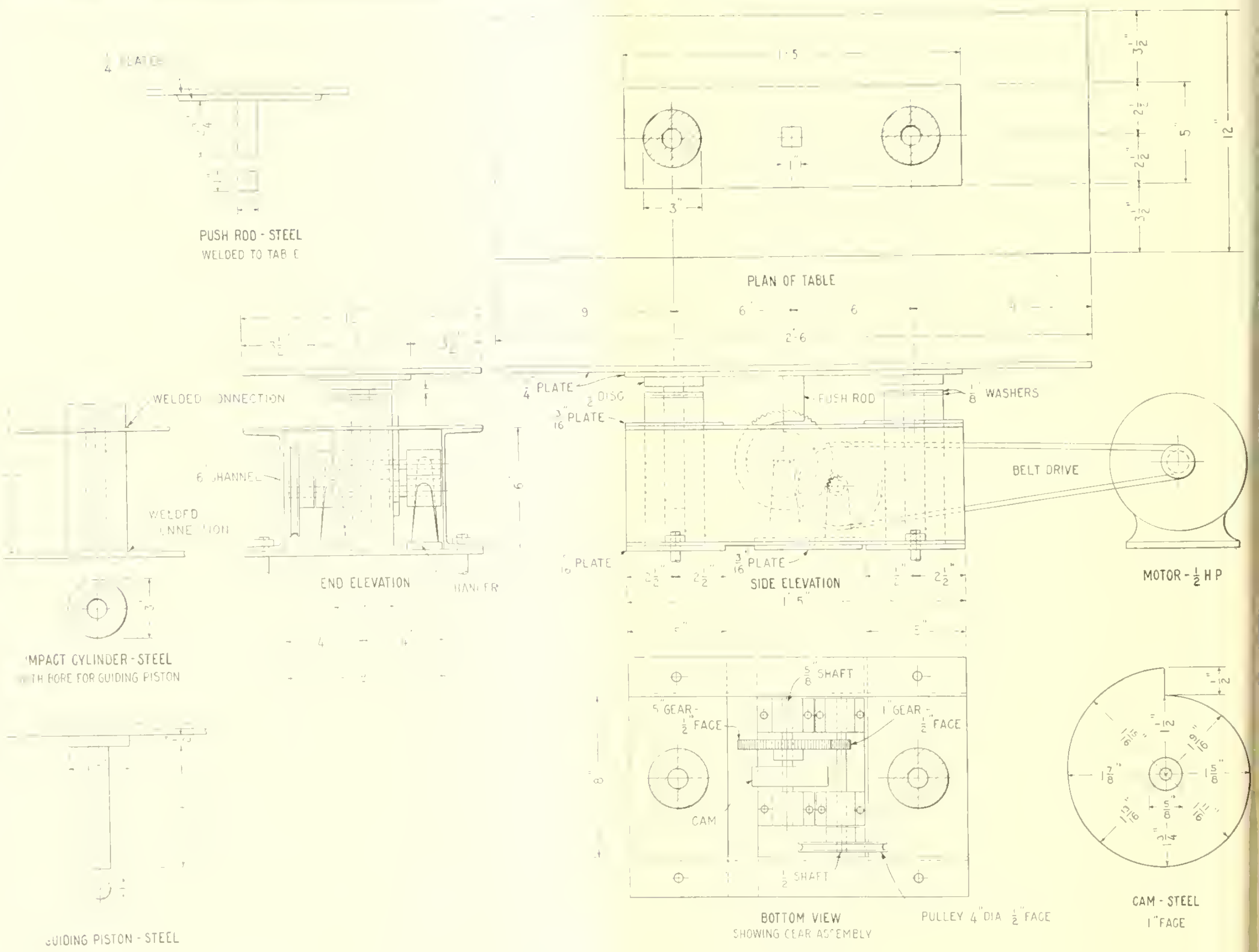

Figure 1.—Mechanical Compaction Table.

rodding. The results indicated that the mechanical method produced curves that were as regular and consistent as those produced by the standard method. Tests were made by different operators using both methods to determine how closely concrete-voids curves could be duplicated by different operators with each method. The machine method was found to be satisfactory in this respect.

The two methods were compared from the standpoint of uniformity of distribution of the ingredients in the molded specimens. This was done by splitting cylinders molded by each method into parts and analyzing each part to determine the amount of each ingredient contained in it. The results of this comparison showed that from the standpoint of uniformity of distribution of the ingredients, the machine, as it was operated, gave satisfactory results.

The two methods were next compared on the basis of strength results for cylinders and beams molded by each method. Comparison was made of the spread in strengths and the average deviation from the arithmetic mean for each individual set and for all sets made by each method. These comparisons showed that the mechanical method of molding strength specimens was as satisfactory as the standard method of hand rodding from the standpoint of uniformity of results.

OPERATION OF MACHINE DETERMINED BY EXPERIMENT

The method of operation of the compacting machine in making density and strength specimens was determined in the following manner: A hemispherical container of one half cubic foot capacity and a depth equal to the pavement thickness was placed on the subgrade in the rear of the mixer on a paving project. After the concrete had been deposited on the subgrade, spread, and had received the final finishing operation, the container full of concrete was removed and the concrete analyzed to determine the amount of each ingredient in it, and also the water and air voids and density of the concrete. Several of these determinations were made over a period of several days and the average value for density and water and air voids was determined. Identical mixtures were prepared in the laboratory from the same materials and specimens were molded on the machine using different heights of drop and numbers of drops. It was found that 340 drops of 1/64 inch in a period of 1 minute produced a density equal to that of concrete in the pavement. This operation of the machine was adopted for the subsequent tests. No appreciable segregation of ingredients was observed in the specimens. For proportions other than those used it might be necessary to vary the operation of the machine somewhat. It is believed, however, that the operation as determined is sufficiently accurate and tended to represent the manipulation of he concrete as placed in the pavement.

MIXTURES USED IN TESTS DESCRIBED

In this investigation two groups of tests were conducted. In the first group the same brand of cement and the same kind of fine and coarse aggregate were used in all mixtures. The proportions of all ngredients were varied and the resulting strengths determined. In the second group three series of tests comprising combinations of different kinds of materials were made in which two brands of cement, one kind of fine aggregate and three kinds of coarse aggregate, were used. The ratio of fine aggregate to cement and he relative water content were constant for all three series. In each series the amount of coarse aggregate was varied from zero to the maximum.

Basis of proportioning.—Proportioning was done by absolute volumes. The symbols used are as follows:

a = Absolute volume of fine aggregate in a unit volume of freshly placed concrete.

b = Absolute volume of coarse aggregate in a unit volume of freshly placed concrete.

c = Absolute volume of cement in a unit volume of freshly placed concrete.

$b_s = \frac{b}{a+b+c}$ = Ratio of the absolute volume of coarse aggregate to the sum of the absolute volumes of fine aggregate, coarse aggregate, and cement in a unit volume of freshly placed concrete.

d = Density or solidity ratio of the freshly placed concrete.

V_c = Voids (air and water) in a unit volume of freshly placed concrete, equals $1-d$.

W_c = Volume of water per unit volume of freshly placed concrete.

$\frac{c}{V_c+c}$ = Cement-space ratio.

w = Relative water content.

$\frac{W_c}{c}$ = Water-cement ratio.

Water content.—The water contents used are expressed in terms of the basic water content, that amount of water which gives maximum density to the particular mixture, as determined from the concrete-voids curve for that mixture. A concrete-voids curve was drawn for every mixture used.

Physical characteristics of materials.—The physical characteristics of the aggregates and cement are shown in table 1. All aggregates were dried to constant weight before they were used.

Specific gravity determinations.—The specific gravities of cements and aggregates were determined in the following manner:

Specific gravity $= \frac{W_a}{W_a - W_w}$ in which W_a represents weight in air, and W_w represents weight when immersed in water. Cement was weighed in air in its natural state. Aggregates were weighed in air in a bone-dry state. Materials were weighed in water after a period of immersion approximating the time the cement and aggregate are in contact with water during the mixing and molding of concrete specimens before the specimens are weighed for the density determination.

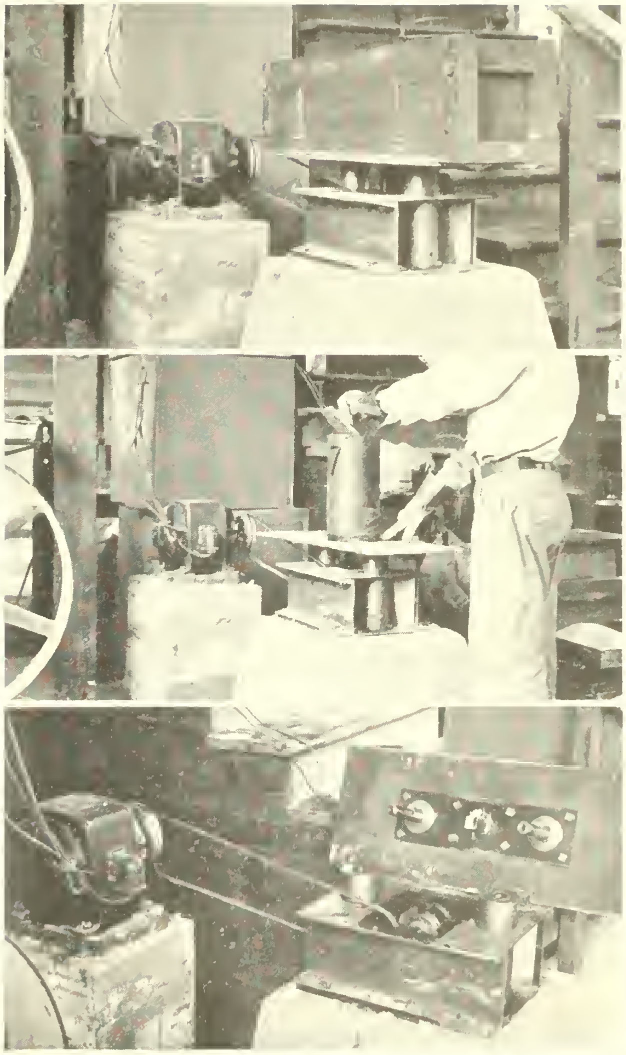

Figure 2.—Mechanical Compacting Machine Being Used to Mold Beam and Cylinder Specimens. Lower Picture Shows Table of Machine Raised to Expose Cam and Driving Mechanism.

Table 1.—*Physical characteristics of materials*

Material	Specific gravity	Percentage of absorption	Mechanical analysis, percentage retained on									Fineness modulus
			1½ in.	¾ in.	⅜ in.	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100	
Fine aggregate, sand, no. 1[1]	2.64	0.00					0.2	3.0	25.8	75.0	96.8	2.01
Coarse aggregate, gravel, no. 2	2.62	.50	0.0	38.2	92.5	98.6	100.0					7.29
Coarse aggregate, crushed limestone, no. 3	2.78	.39	36.6	80.0	94.0	99.7	100.0					8.10
Cement, no. 1	3.27											
Cement, no. 2	3.24											

[1] Similar designations by name and number represent similar materials throughout these tests.

TESTING PROCEDURE

Mixing concrete.—All concrete was mixed by hand on a steel mixing plate. The same operator mixed every batch throughout these tests.

Molding specimens for the density determinations by mechanical means.—A new batch of concrete was mixed for each density determination. The absolute volume of each batch was slightly in excess of the volume of a heavy steel 6- by 12-inch cylinder mold. The entire mold was filled with concrete, then placed on the table of the mechanical compacting machine and subjected to the compacting procedure adopted as standard for these tests. The mold was kept full of concrete during this operation. The concrete was then struck off even with the top of the mold and the density, water voids, and air voids of the concrete determined. Each point on the concrete-voids curves represents one density determination.

Molding strength-test specimens by mechanical means.—A separate batch of concrete was mixed for every 6- by 12-inch cylinder made. Paraffined cardboard cylinder molds were filled completely with concrete and placed on the table of the compacting machine. The machine was then operated to give the standard number of drops, the mold being kept full of concrete to overflowing during this tamping. The concrete was then struck off even with the top of the mold and its density determined. Two separate batches of concrete, one for each of two layers, were mixed for every 6- by 8- by 30-inch beam made. Beams were molded by filling the wooden mold completely full of concrete, using a separate batch for each of two layers. The mold was then placed on the table of the machine and compacted, keeping the mold filled to overflowing during the tamping. The concrete was then struck off even with the top of the mold and the density determination made.

Determining density and voids of concrete.—The outside of the mold containing the specimen was wiped clean and dry, and the weight of the concrete contained in the mold determined. The volume of the batch was determined by the formula:

$$\text{Volume of batch} = \frac{\text{Weight of concrete in original batch} \times \text{Volume of mold}}{\text{Weight of concrete in mold}} \quad \text{(1)}$$

The density of the concrete d in the original batch was determined by the formula:

$$\text{Density of concrete} = \frac{\text{Solid volume of cement and aggregates}}{\text{Volume of batch}} \quad \text{(2)}$$

The total voids in the concrete V_c equals $1-d$ equals W_c plus air voids. W_c, the volume of water per unit volume of freshly placed concrete, was determined by the formula:

$$W_c = \frac{\dfrac{\text{Weight of water added to batch}}{\text{Weight of water per cubic foot}} - \text{Volume of water absorbed by aggregates}}{\text{Volume of batch}} \quad \text{(3)}$$

Air voids equal V_c minus W_c.

Curing and testing.—All strength specimens remained in air for the first 24 hours. They were then placed in the moist room until removed for testing at the age of 28 days. Every strength specimen made was tested and the strength of every break is included in the analyses of results obtained.

FIRST GROUP OF TESTS DESCRIBED

These tests were made in an effort to determine the effect on the strength of concrete of the following: (1) Ratio of fine aggregate to cement; (2) amount of coarse aggregate; (3) amount of water.

Nine different mixtures of cement, fine aggregate, and coarse aggregate were used. All of these mixtures are considered to be within the practical limits of mixtures used in concrete pavement construction.

A concrete-voids curve was drawn for each of the nine mixtures to determine the amount of water required to give maximum density to the concrete (basic water content) and to find the amounts of water to be used in the strength specimens in terms of this basic water content.

After determining the basic water content for each mixture from the concrete-voids curves, six 6- by 12-inch cylinders, two 6- by 8- by 30-inch beams and one slump test were made with each of the nine mixtures for each of the following water contents: 1.00 relative, which is basic water content, 1.10 relative, and 1.20 relative. This made 27 different concrete mixtures.

The 9 mixtures of cement, fine aggregate and coarse aggregate, are as follows:

$$\frac{a}{c}=2.00,\ b_s=\begin{cases}0.45\\0.50\\0.55\end{cases}$$

$$\frac{a}{c}=2.50,\ b_s=\begin{cases}0.45\\0.50\\0.55\end{cases}$$

$$\frac{a}{c}=3.00,\ b_s=\begin{cases}0.45\\0.50\\0.55\end{cases}$$

The corresponding proportions by weight are contained in table 2. No. 2 cement, no. 1 sand, and no. 3 crushed limestone were used.

TABLE 2.—*Proportions of all mixtures by weight*

Absolute volume		Proportions by weight		
b_s	$\frac{a}{c}$	Cement	Fine aggregate	Coarse aggregate
0.45	2.00	1	1.63	2.10
.45	2.50	1	2.03	2.45
.45	3.00	1	2.44	2.80
.50	2.00	1	1.63	2.57
.50	2.50	1	2.03	3.00
.50	3.00	1	2.44	3.43
.55	2.00	1	1.63	3.14
.55	2.50	1	2.03	3.66
.55	3.00	1	2.44	4.18

RESULTS OBTAINED IN FIRST GROUP OF TESTS

Table 3 shows the results of the density determinations from which the concrete-voids curves were drawn. This tabulation is an example of the data required in drawing concrete-voids curves.

Table 4 is a summary of all data collected in this group of tests. This table contains average values for each mixture. The individual values from which these averages were obtained are available.

Table 5 shows the effect of $\frac{a}{c}$, b_s and relative water content, w, on the compressive and flexural strength of the concrete.

Table 6 is a tabulation of the slumps of the 9 different mixtures for each of the 3 relative water contents.

TABLE 3.—*Concrete-voids determinations*

$\frac{a}{c}=2.00 \quad b_s=0.45$

Weight of water	Total weight of materials	Weight of materials in mold	Volume of batch	Density of concrete	Voids		
					Water	Air	Total
Pounds	*Pounds*	*Pounds*	*Cubic feet*				
2.50	36.531	24.039	0.3089	0.6315	0.126	0.2425	0.3685
2.75	36.781	25.566	.2925	.667	.147	.186	.333
3.00	37.031	26.934	.2795	.6975	.168	.1345	3025
3.125	37.156	28.560	.2636	.737	.186	.075	.263
3.25	37.281	29.566	.2563	.761	.199	.040	.239
3.50	37.531	29.773	.2563	.761	.215	.024	.239
3.75	37.781	29.687	.2589	.753	.228	.019	.247
4.00	38.031	29.605	.2612	.747	.245	.008	254
4.25	38.281	29.578	.2631	.742	.255	.003	258

$\frac{a}{c}=2.5 \quad b_s=0.45$

2.75	36.589	25.781	.2885	.676	.149	.175	324
3.00	36.839	27.836	.2691	.725	.175	.100	275
3.25	37.089	29.348	.2569	.759	.199	.042	241
3.375	37.214	29.476	.2567	.759	.207	.034	.241
3.50	37.339	29.594	.2565	.761	.215	.024	.239
3.50	37.339	29.648	.2564	.761	.215	.024	.239
3.75	37.589	29.652	.2577	.757	.229	.014	.243
4.00	37.839	29.508	.2607	.748	.242	.010	252
4.25	38.089	29.516	.2623	.743	.256	.001	.257

$\frac{a}{c}=3.00 \quad b_s=0.45$

2.75	36.445	24.918	.2973	.656	.145	.201	.346
3.00	36.695	26.109	.2857	.682	.165	.153	.318
3.25	36.945	29.136	.2578	.756	.198	.046	244
3.50	37.195	29.461	.2566	.760	.214	.026	.240
3.75	37.445	29.547	.2576	.757	.229	.014	243
4.00	37.695	29.422	.2605	.749	.242	.009	.251
4.25	37.945	29.414	.2622	.7435	.256	.0005	.2565

$\frac{a}{c}=2.00 \quad b_s=0.50$

2.50	36.494	24.695	.3000	.650	.130	.220	.350
2.75	36.744	26.226	.2852	.684	.151	.163	.314
3.00	36.994	29.883	.2517	.775	.186	.039	.225
3.125	37.119	30.020	.2517	.776	.195	.029	.224
3.25	37.244	30.000	.2524	.773	.202	.025	.227
3.50	37.494	30.121	.2536	.769	.217	.014	.231
3.75	37.744	29.828	.2573	.758	.229	.013	242

$\frac{a}{c}=2.50 \quad b_s=0.50$

2.50	36.320	24.601	.3001	.650	.130	.220	.350
2.75	36.570	25.840	.2873	.679	.150	.171	.321
3.00	36.820	29.043	.2577	.757	.182	.061	.243
3.125	36.945	29.719	.2527	.772	.194	.034	.228
3.25	37.070	29.875	.2523	.773	.202	.025	.227
3.50	37.320	29.746	.2551	.765	.215	.020	.235
3.75	37.570	29.789	.2564	.761	.230	.009	239

$\frac{a}{c}=3.00 \quad b_s=0.50$

2.50	36.189	24.309	.3027	.644	.129	.227	.356
2.75	36.439	25.914	.2855	.683	.150	.167	.317
3.00	36.689	28.976	.2574	.758	.183	.059	.242
3.125	36.814	29.398	.2546	.766	.192	.042	234
3.25	36.939	29.668	.2531	.771	.202	.027	229
3.50	37.189	29.734	.2543	.7675	.216	.0165	.2325
3.75	37.439	29.668	.2565	.7505	.230	.0095	2395

$\frac{a}{c}=2.00 \quad b_s=0.55$

2.50	36.495	25.715	.2885	.677	.135	.188	323
2.75	36.745	30.125	.2480	.787	.173	.040	213
2.875	36.860	30.242	.2478	.788	.181	.031	212
3.00	36.995	30.582	.2459	.793	.192	.015	.207
3.25	37.245	30.660	.2470	.790	.206	.004	210
3.50	37.495	30.375	.2509	.778	.219	.003	222

TABLE 3.—*Concrete-voids determinations*—Continued

$\frac{a}{c}=2.50 \quad b_s=0.55$

Weight of water	Total weight of materials	Weight of materials in mold	Volume of batch	Density of concrete	Voids		
					Water	Air	Total
Pounds	*Pounds*	*Pounds*	*Cubic feet*				
2.50	36.298	26.234	.2808	.695	.139	.166	305
2.75	36.548	29.516	.2517	.776	.171	.053	.224
2.875	36.673	30.027	.2483	.786	.181	.033	211
3.00	36.798	30.074	.2488	.784	.189	.027	.216
3.00	36.789	30.187	.2478	.787	.189	.024	.213
3.25	37.048	30.258	.2489	.784	.204	.012	.216
3.50	37.298	30.265	.2497	.780	.220	009	220

$\frac{a}{c}=3.00 \quad b_s=0.55$

2.50	36.181	25.617	.2871	.680	.135	.185	.320
2.75	36.431	28.328	.2615	.746	.164	.090	.254
2.875	36.556	30.059	.2472	.789	.182	.029	.211
2.875	36.556	29.406	.2527	.772	.178	.050	.228
3.00	36.681	29.957	.2489	.781	.188	.018	216
3.00	36.681	30.164	.2473	.789	.190	.021	.211
3.25	36.931	30.156	.2489	.784	.204	.012	.216
3.50	37.181	30.023	.2518	.774	.218	.008	.226

Table 7 shows the values and changes in values of W_c and V_c at maximum density or basic water content for the different values of $\frac{a}{c}$ and b_s.

Table 8 shows the densities taken from the concrete-voids curves and the densities as determined for the strength specimens made with corresponding mixtures.

Table 9 shows the average of individual percentage variations in strength from the arithmetic mean of each set of specimens made with each mixture.

Figure 3 shows, for each value of $\frac{a}{c}$, the concrete-voids curve for each of the three values of b_s. These curves are replotted in figure 4 which shows for each value of b_s the concrete-voids curve for each value of $\frac{a}{c}$.

Figure 5 shows the effect of variations in $\frac{a}{c}$, b_s, and relative water content on the compressive and flexural strength of concrete. Each point shown on the curve is the average of 6 breaks (3 breaks for each of the 2 beams in the case of flexure.).

Figure 6 shows the relation of the water-cement ratio to $\frac{a}{c}$ and b_s for the 27 mixtures used.

Figures 7 and 8 show the effect of the water-cement ratio on the compressive and flexural strength of the concrete. Each point on these figures is the average of 6 breaks.

Figure 9 consists of photographs showing the slumped concrete for each mixture and showing the beam breaks with the exposed particles of coarse aggregate on one of the broken ends.

RESULTS OF FIRST GROUP OF TESTS DISCUSSED

The two outstanding results developed by these tests are: For a particular value of $\frac{a}{c}$ a relation exists between the values of b_s and the value of W_c and V_c for basic water content. The same relation likewise exists between the values of b_s and the points corresponding to other relative water contents computed from the basic. This relation is shown in figure 3. In each figure the points of corresponding relative

TABLE 4.—*Summary of data from first group of tests*

$\frac{a}{c}$	b_s	Relative water content	Data from concrete-voids determinations [1]					Data from strength specimens [2]																			
				Voids				Cylinders	Voids							Beams	Voids										
			Volume of batch	Water	Air	Total	Density	Volume of batch	Water	Air	Total	Density	Compressive strength	Average of individual percentage variations from arithmetic mean	Maximum spread in strength	Volume of batch	Water	Air	Total	Density	Flexural strength	Average of individual percentage variations from arithmetic mean	Maximum spread in strength	$\frac{W_c}{c}$	Gallons of water per sack of cement	Sacks of cement per cubic yard of concrete	$\frac{c}{V_c+c}$
			Cubic feet					*Cubic feet*					*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Cubic feet*					*Lbs. per sq. in.*		*Lbs. per sq. in.*				
2.00	0.45	1.0	0.256	0.2045	0.0335	0.238	0.762	0.255	0.205	0.030	0.235	0.765	4,716	10.0	1,217	1.033	0.203	0.042	0.245	0.755	771	8.3	266	1.47	5.11	8.12	0.373
2.00	.45	1.1	.2575	.225	.0175	.2425	.7575	.256	.226	.013	.239	.761	4,432	3.0	410	1.038	.223	.026	.249	.751	733	4.8	123	1.63	5.66	8.07	.368
2.00	.45	1.2	.261	.2455	.0065	.252	.748	.260	.246	.002	.248	.752	3,861	6.2	714	1.046	.244	.010	.254	.746	690	6.7	137	1.80	6.24	7.97	.356
2.50	.45	1.0	.256	.2065	.0315	.238	.762	.254	.208	.024	.232	.768	3,546	3.9	577	1.027	.206	.033	.239	.761	723	3.5	77	1.73	6.02	6.98	.341
2.50	.45	1.1	.2575	.227	.0155	.2425	.7575	.256	.229	.009	.238	.762	3,235	3.0	287	1.027	.227	.016	.243	.757	694	2.5	73	1.92	6.66	6.93	.334
2.50	.45	1.2	.2605	.248	.0035	.2515	.7485	.259	.249	−.002	.247	.753	2,721	6.1	505	1.048	.247	.009	.256	.744	648	6.4	127	2.12	7.36	6.84	.323
3.00	.45	1.0	.2565	.2105	.0295	.240	.760	.254	.216	.018	.234	.766	2,951	2.5	346	1.029	.214	.026	.240	.760	620	7.8	162	2.06	7.16	6.09	.309
3.00	.45	1.1	.2585	.2315	.0145	.246	.754	.257	.237	.004	.241	.759	2,544	2.7	191	1.049	.232	.024	.256	.744	552	6.4	83	2.28	7.92	6.03	.301
3.00	.45	1.2	.262	.2525	.004	.2565	.7435	.261	.253	.000	.253	.747	1,807	4.1	287	1.043	.254	−.001	.253	.747	490	4.9	87	2.48	8.63	5.94	.287
2.00	.50	1.0	.251	.1935	.0295	.223	.777	.248	.196	.017	.213	.787	4,782	5.4	782	1.012	.193	.036	.229	.771	766	2.0	45	1.50	5.22	7.58	.380
2.00	.50	1.1	.2535	.213	.0175	.2305	.7695	.251	.215	.008	.223	.777	3,975	4.2	672	1.029	.210	.030	.240	.760	773	2.2	66	1.67	5.80	7.49	.366
2.00	.50	1.2	.2565	.232	.0075	.2395	.7605	.256	.233	.004	.237	.763	3,295	7.6	693	1.019	.233	.001	.234	.766	674	8.3	272	1.84	6.40	7.35	.348
2.50	.50	1.0	.252	.1985	.0285	.227	.773	.250	.201	.018	.219	.781	3,760	3.1	294	1.004	.199	.024	.223	.777	696	2.6	65	1.81	6.28	6.45	.336
2.50	.50	1.1	.254	.2185	.013	.2315	.7685	.252	.220	.005	.225	.775	2,958	4.7	495	1.030	.216	.026	.242	.758	600	8.3	167	2.00	6.95	6.39	.328
2.50	.50	1.2	.257	.238	.002	.240	.760	.256	.240	−.003	.237	.763	2,105	3.9	375	1.032	.237	.006	.243	.757	529	4.1	54	2.21	7.67	6.30	.314
3.00	.50	1.0	.253	.202	.027	.229	.771	.252	.203	.024	.227	.773	2,478	3.4	361	1.017	.201	.032	.233	.767	571	6.1	141	2.11	7.32	5.59	.298
3.00	.50	1.1	.257	.222	.014	.236	.764	.254	.225	.006	.231	.769	2,011	3.6	184	1.031	.221	.021	.242	.758	492	4.6	65	2.35	8.17	5.55	.292
3.00	.50	1.2	.259	.2425	.0035	.246	.754	.258	.244	−.001	.243	.757	1,290	8.1	308	1.029	.214	−.002	.242	.758	410	7.0	103	2.59	8.98	5.47	.279
2.00	.55	1.0	.246	.1815	.025	.2065	.7935	.245	.182	.021	.203	.797	4,314	9.8	1,622	1.012	.177	.052	.229	.771	766	4.9	156	1.53	5.33	6.91	.369
2.00	.55	1.1	.247	.1995	.011	.2105	.7895	.247	.200	.010	.210	.790	3,544	7.0	666	1.010	.195	.032	.227	.773	692	3.8	111	1.70	5.89	6.84	.359
2.00	.55	1.2	.2505	.218	.003	.221	.779	.250	.218	.002	.220	.780	3,061	6.2	576	1.010	.216	.012	.228	.772	675	5.5	111	1.88	6.52	6.76	.345
2.50	.55	1.0	.248	.1875	.025	.2125	.7875	.246	.189	.017	.206	.794	3,514	5.5	803	.997	.186	.031	.217	.783	684	3.7	86	1.86	6.48	5.89	.330
2.50	.55	1.1	.249	.2065	.0095	.216	.784	.248	.207	.006	.213	.787	2,946	9.2	690	1.014	.202	.028	.230	.770	605	7.9	147	2.06	7.15	5.85	.321
2.50	.55	1.2	.252	.225	.000	.225	.775	.252	.225	−.001	.224	.776	1,864	5.1	396	1.007	.225	.000	.225	.775	507	3.0	54	2.27	7.89	5.77	.307
3.00	.55	1.0	.248	.1905	.023	.2135	.7865	.247	.192	.017	.209	.791	2,776	4.3	355	1.010	.187	.040	.227	.773	581	7.1	141	2.17	7.53	5.14	.297
3.00	.55	1.1	.250	.2095	.011	.2205	.7795	.249	.210	.007	.217	.783	1,991	6.3	432	1.019	.206	.027	.233	.767	480	3.6	62	2.40	8.35	5.09	.287
3.00	.55	1.2	.254	.2285	.004	.2325	.7675	.252	.231	−.006	.225	.775	1,353	4.4	241	1.015	.228	.003	.231	.769	384	8.5	110	2.66	9.25	5.03	.278

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[1] Taken from concrete-voids curves.

[2] Each value is average of 6 values except beam densities and voids which are averages of 2 values.

TABLE 5. *Effect of* $\frac{a}{c}$, b_s, *and relative water content,* w, *on the compressive and flexural strength of concrete*

WATER CONTENT VARIABLE

$\frac{a}{c}$	b_s	Basic		$w=1.10$				$w=1.20$			
		Compressive	Flexural	Compressive	Change from basic	Flexural	Change from basic	Compressive	Change from 1.10 relative	Flexural	Change from 1.10 relative
		Pounds per sq. in.	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*
2.0	0.45	4,716	771	4,432	−284	733	−38	3,861	−571	690	−43
2.5	.45	3,546	723	3,235	−311	694	−29	2,721	−514	648	−46
3.0	.45	2,951	620	2,544	−407	552	−68	1,807	−737	490	−62
2.0	.50	4,782	766	3,975	−807	773	−93	3,295	−680	674	−99
2.5	.50	3,760	696	2,958	−802	600	−96	2,105	−853	529	−71
3.0	.50	2,478	571	2,011	−467	492	−79	1,290	−721	410	−82
2.0	.55	4,314	766	3,544	−770	692	−74	3,061	−483	675	−17
2.5	.55	3,514	684	2,946	−568	605	−79	1,864	−1,082	507	−98
3.0	.55	2,776	581	1,991	−785	480	−101	1,353	−638	384	−96
Average					−589		−73		−698		−68

SAND-CEMENT RATIO VARIABLE

b	Relative water content, w	$\frac{a}{c}=2.0$		$\frac{a}{c}=2.5$				$\frac{a}{c}=3.0$			
		Compressive	Flexural	Compressive	Change from $\frac{a}{c}=2.0$	Flexural	Change from $\frac{a}{c}=2.0$	Compressive	Change from $\frac{a}{c}=2.5$	Flexural	Change from $\frac{a}{c}=2.5$
		Pounds per sq. in.	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*
0.45	1.0	4,716	771	3,546	−1,170	723	−48	2,951	−595	620	−103
.45	1.1	4,432	733	3,235	−1,197	694	−39	2,544	−691	552	−142
.45	1.2	3,861	690	2,721	−1,140	648	−42	1,807	−914	490	−158
.50	1.0	4,782	766	3,760	−1,022	696	−70	2,478	−1,282	571	−125
.50	1.1	3,975	773	2,958	−1,017	600	−173	2,011	−947	492	−108
.50	1.2	3,295	674	2,105	−1,190	529	−145	1,290	−815	410	−119
.55	1.0	4,314	766	3,514	−800	684	−82	2,776	−738	581	−103
.55	1.1	3,544	692	2,946	−598	605	−87	1,991	−955	480	−125
.55	1.2	3,061	675	1,864	−1,197	507	−168	1,353	−511	384	−123
Average					−1,037		−95		−828		−123

TABLE 5.—*Effect of $\frac{a}{c}$, b_s, and relative water content, w, on the compressive and flexural strength of concrete*—Continued

COARSE AGGREGATE CONTENT VARIABLE

Relative water content, *w*	$\frac{a}{c}$	$b_s=0.45$		$b_s=0.50$				$b_s=0.55$			
		Compressive	Flexural	Compressive	Change from $b_s=0.45$	Flexural	Change from $b_s=0.45$	Compressive	Change from $b_s=0.50$	Flexural	Change from $b_s=0.50$
		Pounds per sq. in.	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq.-in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*
1.0	2.0	4,716	771	4,782	+66	766	−5	4,314	−468	766	0
1.1	2.0	4,432	733	3,975	−457	773	+40	3,544	−131	692	−81
1.2	2.0	3,861	690	3,295	−566	674	−16	3,061	−234	675	+1
1.0	2.5	3,546	723	3,760	+114	676	−27	3,514	−246	684	−12
1.1	2.5	3,235	694	2,958	−277	600	−94	2,946	−12	605	+5
1.2	2.5	2,721	648	2,105	−616	529	−119	1,864	−241	507	−22
1.0	3.0	2,951	620	2,478	−473	571	−49	2,776	+298	581	+10
1.1	3.0	2,544	552	2,011	−533	492	−60	1,991	−20	480	−12
1.2	3.0	1,807	490	1,290	−517	410	−80	1,353	+63	384	−26
Average					−362		−46		−143		−16

TABLE 6.—*Tabulation of slumps for all mixtures*

$\frac{a}{c}$	b_s	Slump in inches for relative water content of [1]—		
		1.00	1.10	1.20
2.00	0.45	1.5	5.0	7.0
	.50	2.5	5.5	7.0
	.55	1.5	4.5	6.5
2.50	.45	2.0	5.0	7.5
	.50	1.5	4.5	7.5
	.55	1.5	5.0	6.5
3.00	.45	1.0	4.0	6.5
	.50	2.0	4.5	7.5
	.55	2.0	5.0	7.0
Average		1.7	4.7	7.0

[1] Slump tests made in accordance with A.S.T.M. specifications.

TABLE 7.—*Values and changes in values of voids V_c and water W_c at maximum density (basic water content) for different values of $\frac{a}{c}$ and b_s.*

b_s	Sand-cement ratio, $\frac{a}{c}$					
	2.00		2.50		3.00	
	V_c	W_c	V_c	W_c	V_c	W_c
0.45	0.238	0.2045	0.238	0.2065	0.240	0.2105
.50	.223	.1935	.227	.1985	.229	.2020
.55	.2065	.1815	.2125	.1875	.2135	.1905

	Sand-cement ratio, $\frac{a}{c}$		
	2.00	2.50	3.00
Change in density at basic water with b_s changing from 0.45 to 0.50	+0.015	+0.011	+0.011
Change in density at basic water with b_s changing from 0.50 to 0.55	+.0165	+.0145	+.0155
Change in water at basic with b_s changing from 0.45 to 0.50	−.0115	−.0085	−.0085
Change in water at basic with b_s changing from 0.50 to 0.55	−.012	−.011	−.0115

TABLE 8.—*Comparison of densities from concrete-voids curves with densities of strength specimens*

$\frac{a}{c}$	b_s	Relative water content	Densities		
			From concrete-voids curves	As determined by strength specimens for—	
				Cylinders	Beams
2.0	0.45	1.0	0.762	0.765	0.755
2.0	.45	1.1	.7575	.761	.751
2.0	.45	1.2	.748	.751	.746
2.5	.45	1.0	.762	.768	.761
2.5	.45	1.1	.7575	.762	.757
2.5	.45	1.2	.7485	.753	.741
3.0	.45	1.0	.760	.765	.760
3.0	.45	1.1	.754	.759	.744
3.0	.45	1.2	.7435	.747	.747
2.0	.50	1.0	.777	.787	.771
2.0	.50	1.1	.7695	.777	.760
2.0	.50	1.2	.7605	.763	.766
2.5	.50	1.0	.773	.781	.777
2.5	.50	1.1	.7685	.775	.758
2.5	.50	1.2	.760	.763	.757
3.0	.50	1.0	.771	.773	.767
3.0	.50	1.1	.764	.769	.758
3.0	.50	1.2	.754	.757	.758
2.0	.55	1.0	.7935	.797	.771
2.0	.55	1.1	.7895	.790	.773
2.0	.55	1.2	.779	.780	.772
2.5	.55	1.0	.7875	.794	.783
2.5	.55	1.1	.784	.787	.770
2.5	.55	1.2	.775	.776	.775
3.0	.55	1.0	.7865	.791	.773
3.0	.55	1.1	.7795	.783	.767
3.0	.55	1.2	.7675	.775	.769

TABLE 9.—*Average of individual percentage variations in strength from arithmetic mean of 6 breaks*

$\frac{a}{c}$	b_s	Cylinders			Beams		
		Relative water content			Relative water content		
		1.0	1.1	1.2	1.0	1.1	1.2
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2.0	0.45	10.0	3.0	6.2	8.3	4.8	6.7
2.5	.45	3.9	3.0	6.1	3.5	2.5	6.4
3.0	.45	2.5	2.7	4.1	7.8	6.4	4.9
2.0	.50	5.4	4.2	7.6	2.0	2.2	8.3
2.5	.50	3.1	4.7	3.9	2.6	8.3	4.1
3.0	.50	3.4	3.6	8.1	6.1	4.6	7.0
2.0	.55	9.8	7.0	6.2	4.9	3.8	5.5
2.5	.55	5.5	9.2	5.1	3.7	7.9	3.0
3.0	.55	4.3	6.3	4.1	7.1	3.6	8.5
Average		5.3	4.9	5.7	5.1	4.9	6.0
Grand average				5.3			5.3

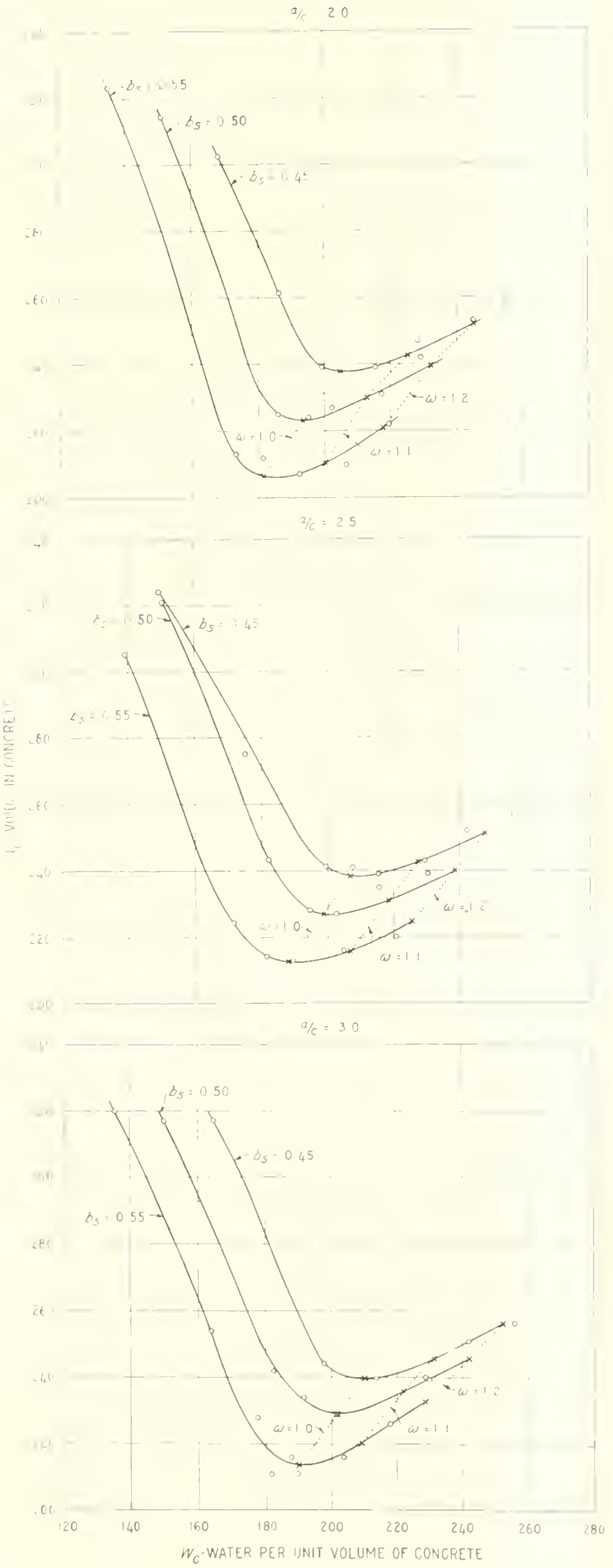

Figure 3.—Voids in Concrete Corresponding to Different Water Contents With $\frac{a}{c}$ Constant for Each Group of Curves.

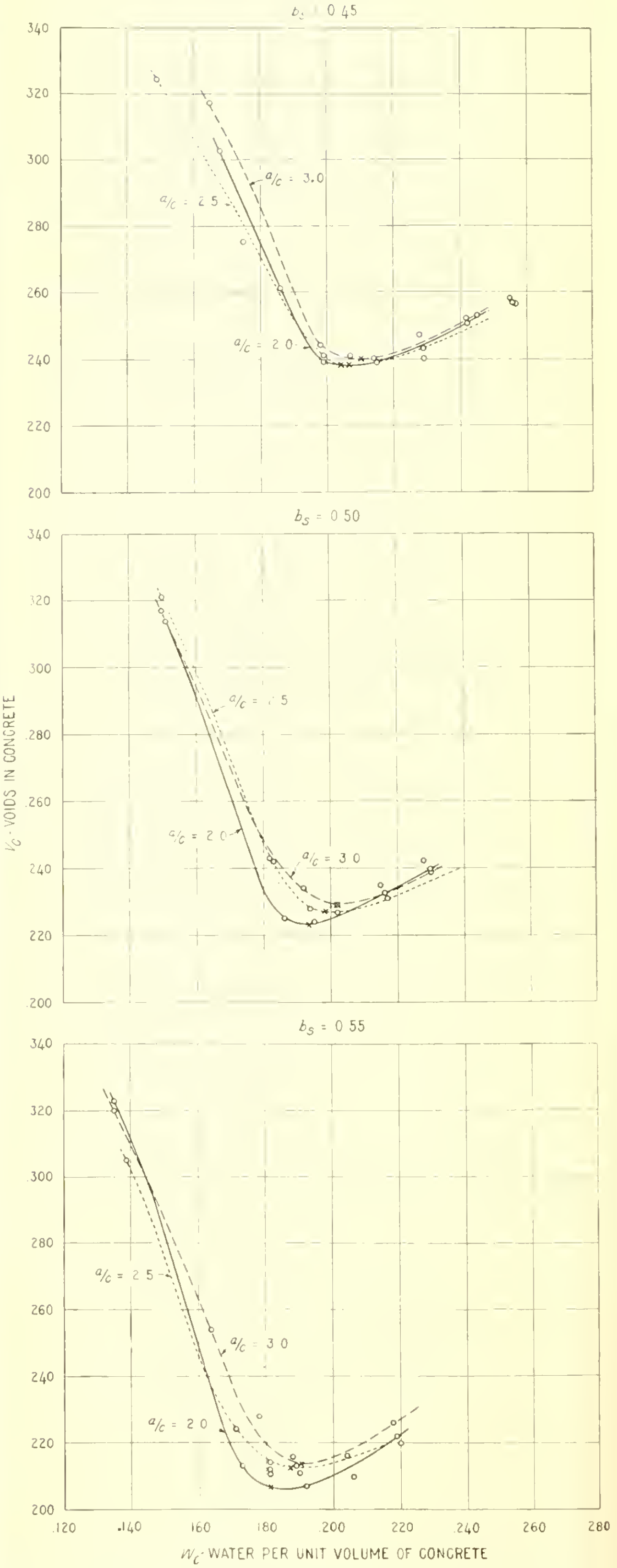

Figure 4.—Voids in Concrete Corresponding to Different Water Contents with b_s Constant for Each Group of Curves.

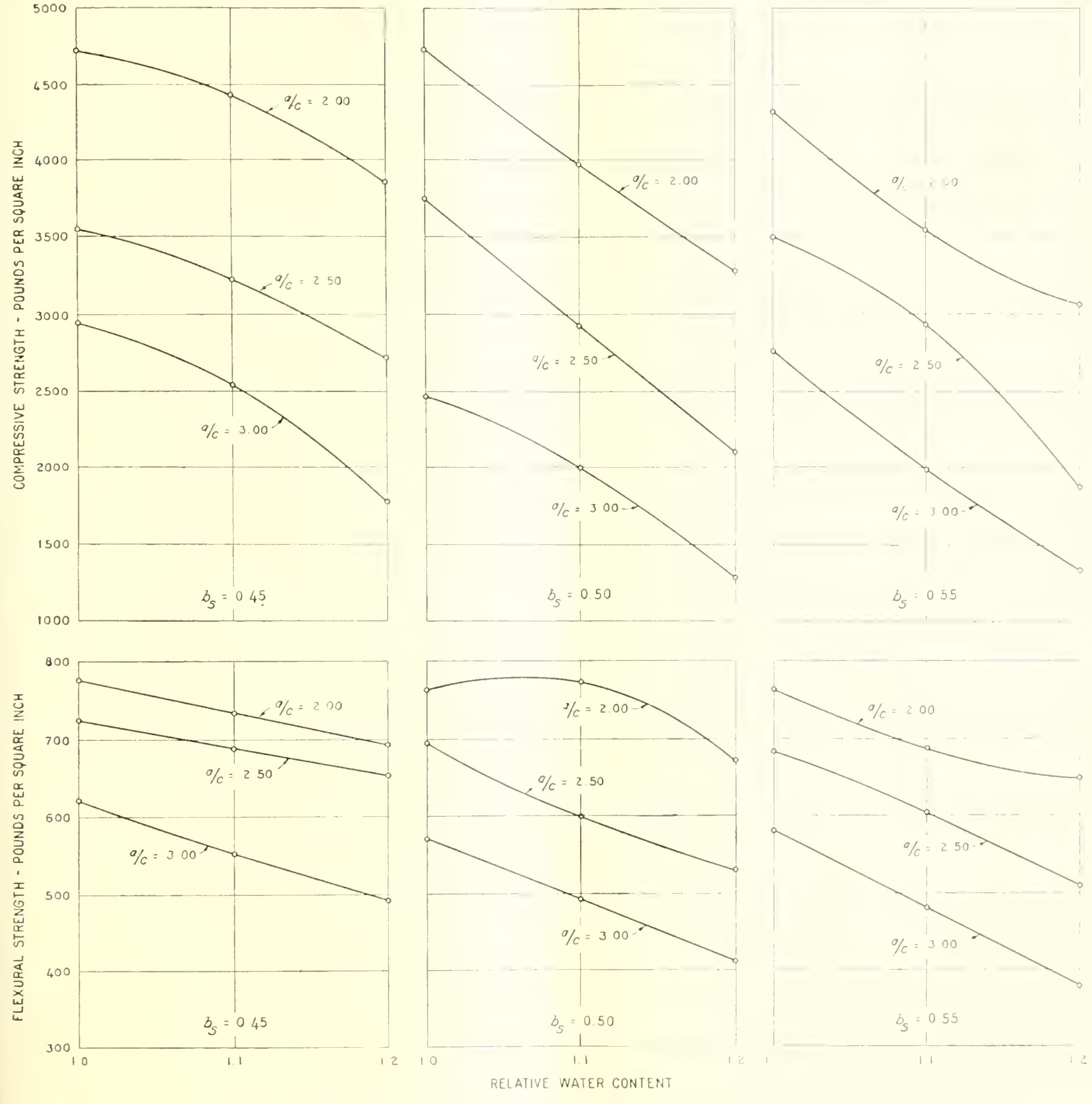

Figure 5.—Effect of Variation in $\frac{a}{c}$, b_s and Relative Water Content on Strength of Concrete.

water content on the three b_s curves fall on a line that is approximately straight.

A relation exists between the values of $\frac{a}{c}$ and the points corresponding to each relative water content for each particular value of b_s. The points of basic water content are shown on the three $\frac{a}{c}$ curves for each value of b_s in figure 4. This relation is not as definite as that shown in figure 3.

For a particular relative water content the slump of the concrete is nearly constant regardless of the values of $\frac{a}{c}$ and b_s used in the mixture. The slumps of the 9 concrete mixtures for each of the 3 relative water contents, 1.00, 1.10, and 1.20, are shown in table 6. There are some variations in the slumps as shown for each relative water content. Individual slumps, however, do not vary greatly from the average. The variations are considered to be within the probable error within which the slump test can be made.

Other results shown by this test follow:

The basic water content or the amount of water required to give maximum density to a concrete mixture, may be different for every different combinations of the ingredients.

A concrete mixture having maximum density (as molded in this test by a new method designed to dupli-

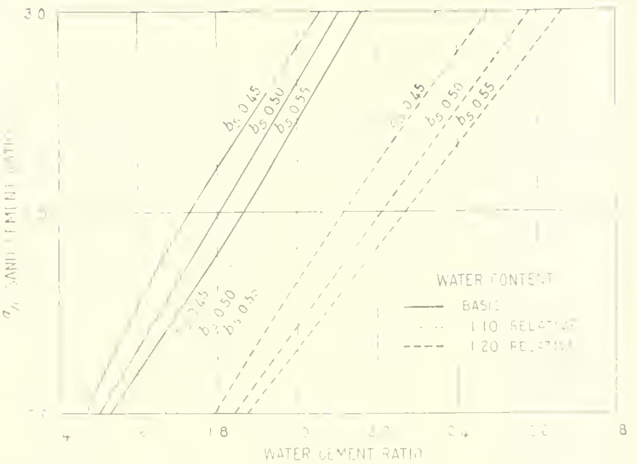

Figure 6.—Relation of Water-Cement Ratio to $\frac{a}{c}$ and b_s.

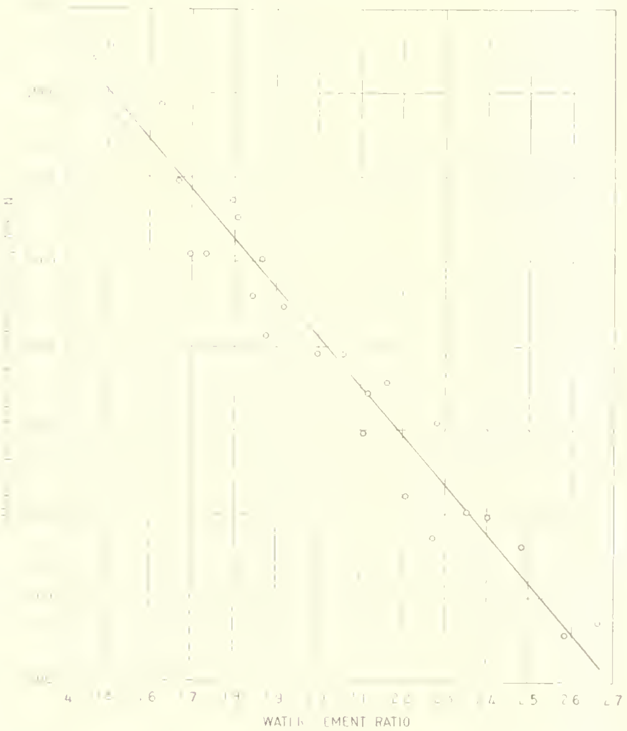

Figure 7.—Effect of Water-Cement Ratio on Compressive Strength.

cate the density of the concrete in place in a pavement) contains both water and air voids. Combinations of the particular materials used in this test, require a value of w greater than 1.20 relative to eliminate all air voids. The slump corresponding to this relative water content of 1.20 is 7 inches.

With a fixed ratio of sand to cement the amount of water per unit volume of concrete required to give maximum density and the total voids in the mixture decreases as the coarse aggregate content of the mixture is increased. This relation is shown in figure 3 and table 7. With a given ratio of coarse aggregate to total solid volume the amount of water required to give maximum density and the total voids in the mixture increases as the ratio of sand to cement increases. The increase is slight for the range in sand and cement contents used in this test. This relation is shown in figure 4 and table 7.

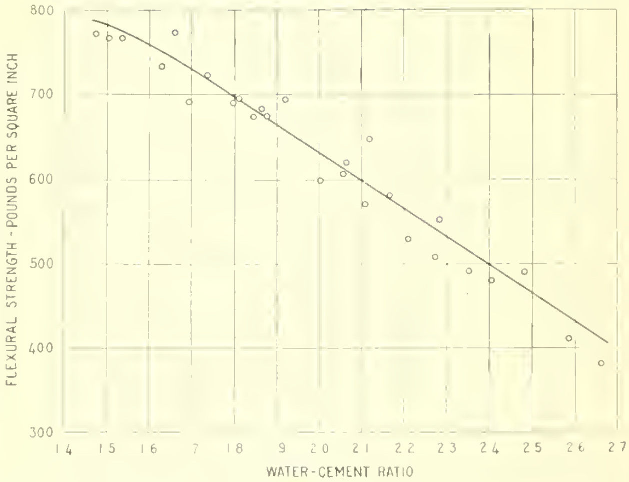

Figure 8.—Effect of Water-Cement Ratio on Flexural Strength.

The density of the concrete in every strength specimen was determined immediately after the specimen was molded. The closeness with which these determinations approach the densities shown on the concrete-voids curves for the corresponding combinations of $\frac{a}{c}$, b_s, and w is shown in table 8. The strength-specimen density values are averages for 6 cylinders and for 2 beams made with each combination. There is some irregularity between the densities of the test specimens and the densities of corresponding mixtures as determined from the concrete-voids curves. These discrepancies, which are not excessive, can be accounted for in part, by the fact that the concrete-voids specimens were molded in a heavy steel cylinder mold whereas the test cylinders were molded in light cardboard molds and the beams were molded in wooden molds. The difference in the weights and types of molds may have caused a difference in the magnitude of the impacts delivered to each. The wooden molds for beams were not absolutely watertight, and it was more difficult to determine the volume of the concrete in the mold due to the large area to be struck off.

In this test (in which water contents equal to or higher than basic were used) the amount of water required to give maximum density to a particular combination of materials was found to be that water content which gave maximum strength to the concrete made with that particular combination. The strength of a concrete mixture decreased as its relative water content increased, as the value of $\frac{a}{c}$ increased and as the value of b_s increased. The results of the strength tests showing graphically the relation between strength, $\frac{a}{c}$, b_s and w are shown in figure 5. The actual variations in strength caused by variations in the values of $\frac{a}{c}$, b_s and w are shown in table 5. It should be borne in mind that changes in the values of $\frac{a}{c}$, b_s and w are accompanied by changes in the water-cement ratio. These changes are shown in table 4 for all mixtures. An analysis of this table shows that for the 9 different combinations of $\frac{a}{c}$ and b_s the average decreases in

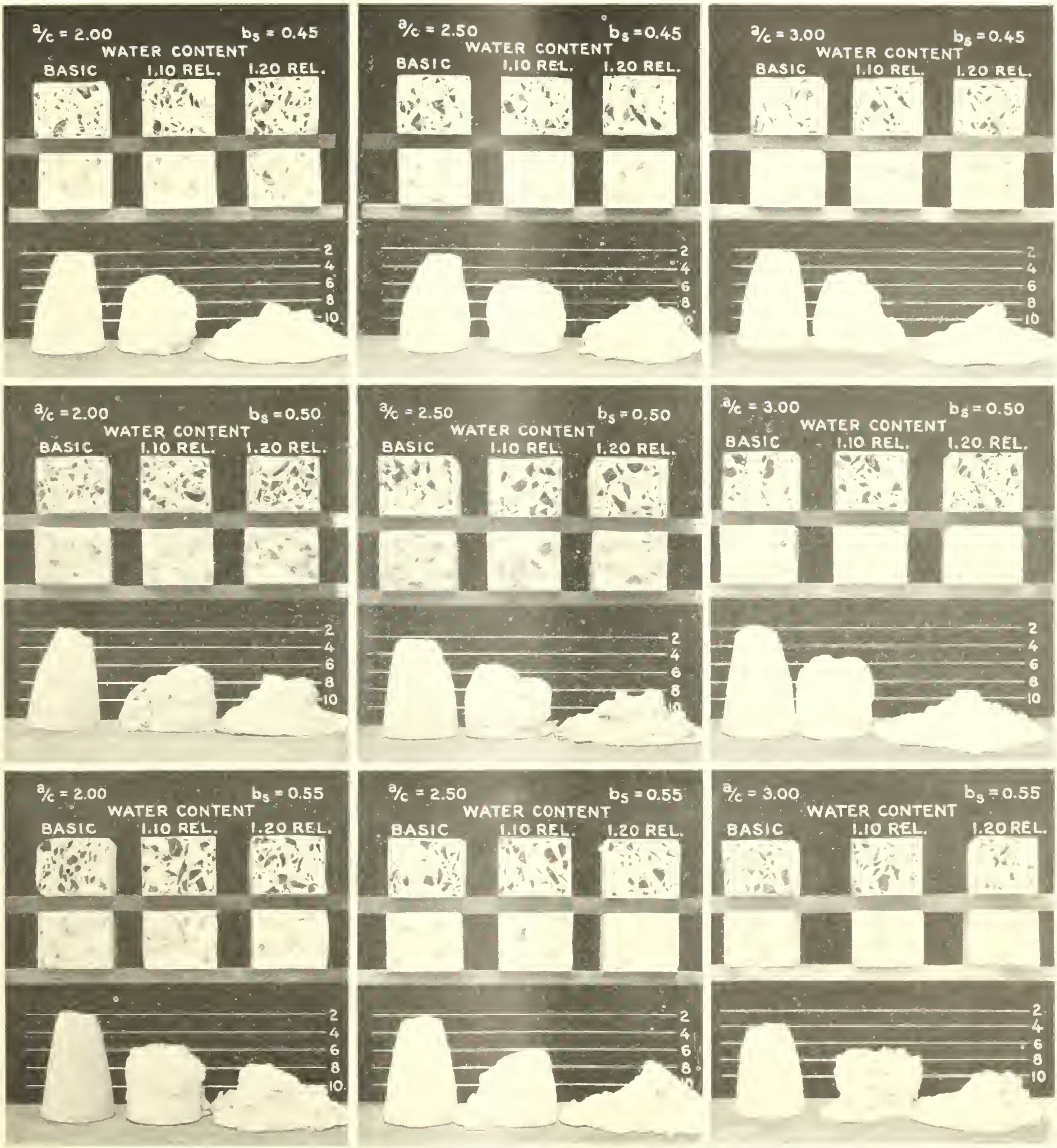

FIGURE 9.—SLUMP TEST SPECIMENS AND CORRESPONDING BEAM BREAKS FOR VALUES OF $\frac{a}{c}$, b_s AND RELATIVE WATER CONTENTS AS INDICATED. COARSE AGGREGATE HAS BEEN PAINTED ON UPPER BEAM BREAK IN EACH CASE

strengths due to increase in the relative water content are as follows:

Change in strength due to change in water content

	Pounds per square inch	Percent
From basic to 1.10 relative:		
Compression	−589	16
Flexure	−73	11
From 1.10 relative to 1.20 relative.		
Compression	−698	23
Flexure	−68	11

For the nine different combinations of b_s and w the average decreases in strength due to increase in the value of $\frac{a}{c}$ are as follows:

	Pounds per square inch	Percent
Change in $\frac{a}{c}$ from 2.00 to 2.50.		
Compression	−1,037	26
Flexure	−95	13
Change in $\frac{a}{c}$ from 2.50 to 3.00:		
Compression	−828	28
Flexure	−123	19

For the nine different combinations of w and $\frac{a}{c}$ the average decreases in strength due to increase in the value of b_s are as follows:

	Pounds per square inch	Percent
Change in b_s from 0.45 to 0.50:		
Compression	−362	11
Flexure	−46	7
Change in b_s from 0.50 to 0.55:		
Compression	−143	5
Flexure	−16	3

The results of this analysis show that with the particular materials used a change of 0.1 in the value of w, the relative water content, caused a change in strength of 589 to 698 pounds in compression and of 68 to 73 pounds in flexure. A change of 0.5 in $\frac{a}{c}$, the sand-cement ratio, caused a change in strength of 828 to 1,037 pounds in compression and of 95 to 123 pounds in flexure. A change in b_s of 0.05 caused a change in strength of 143 to 362 pounds in compression and of 16 to 46 pounds in flexure.

The results of these tests indicate the effect of varying the proportions of ingredients on the strength of concrete. The experience in expressing proportions on the basis of solid volumes was very satisfactory. Volume relations were being studied and direct expression of these relations was more convenient, in this study, than indirect expression with specific gravity as a factor influencing conclusions.

The range in the values of b_s in this test was not sufficiently great to reflect the effect of the amount of coarse aggregate on the strength of concrete. The second group of tests described in this report show this effect in concrete mixtures in which the values of b_s range from zero to the maximum.

A definite relation is shown to exist between the water-cement ratio and the strength of concrete both in compression and flexure. This relation is shown in figures 7 and 8. Each point in these figures is the average of six breaks. The points fall within a band which approaches a straight line. The width of the band is presumably due to irregularities in mixing, molding, curing, capping, and testing and not to variation in the water-cement relationship.

The strengths of concrete mixtures composed of different proportions of cement, aggregates, and water bear no direct relation to their respective densities. As an example the mixture with $\frac{a}{c}=2.00$, $b_s=0.45$, and $w=1.00$ has a density of 0.7650 and a compressive strength of 4,716 pounds per square inch; the mixture with $\frac{a}{c}=3.00$, $b_s=0.55$, and $w=1.20$ has a density of 0.7746 and a compressive strength of 1,353 pounds per square inch. The densities and corresponding strengths for all mixtures are shown in table 4. The density determination appears to have its greatest value in determining the amount of water required to give maximum density to a particular combination of materials under a particular method of placing. The strength of a particular mixture, however, can be expected to be greater with maximum density than with any other density resulting from greater amounts of water. The actual density obtained can be expected to be different for different methods of placing.

There is a relation between the cement-space ratio and the strength of concrete because this ratio involves the amount of cement. This relationship, however, is not definite like the water-cement ratio because it involves the total void space, and the voids or densities for different mixtures bear no direct relation to strength. The cement-space ratio for every mixture is shown in table 4.

The amount of water required to give maximum density to a particular combination of materials can be determined with a reasonable degree of accuracy on the basis of density determinations made by mechanical means. This is shown in table 3 and in the concrete-voids curves of figure 3. These curves are remarkably regular considering the fact that each curve is described by only a few points and each point represents but one density determination.

The mechanical method of molding concrete strength specimens is considered to be comparable with the standard hand method from the standpoint of the consistency of strength results. The data in table 9 show the average of individual percentage variations in strength from the arithmetic mean for each group of specimens for each mixture. The grand average of all these variations in all mixes is 5.3 percent for both cylinders and beams.

SECOND GROUP OF TESTS MADE

A second group of tests was made for two purposes: First, to check the relations found to exist in the first group, and second, to determine the effect of the amount of coarse aggregate in a concrete mixture on the strength of the resulting concrete. This group consisted of three series. A value of $\frac{a}{c}$ of 2.576 and a value of w of 1.10 relative, was used in every mixture in all three series. The value of b_s in series 1 and 3 was varied by increments of 0.10 and in series 2 by increments slightly greater than 0.10, from 0.00 to or slightly above the point at which the mortar was sufficient to fill the void spaces in the mass of coarse aggregate as placed in the molds. This resulted in 8 concrete-voids curves for series 1, 9 curves for series 2, and 8 curves for series 3. Strength specimens were made only with those mixtures in which the mortar was sufficient to fill the void spaces in the coarse aggregate. This resulted in 7 different mixtures for series 1 and 8 different mixtures for series 2 and 3, making 23 mixtures from which strength specimens and slump tests were made. Two different kinds of coarse aggregate and two different brands of cement were used. The same kind of sand was used in all tests. The materials used in each series are shown in table 10.

Density determinations were made and concrete-voids curves were drawn for every mixture in each series. Each curve was used in determining the basic water content for each mixture; and for determining the amount of water and the total voids for a relative water content of 1.10, which was the water content used in all

TABLE 10.—*Materials used in each series of tests*

Series	Cement	Fine aggregate	Coarse aggregate
1	No. 2	Sand, no. 1	Crushed limestone, no. 3.
2	No. 1	do	Gravel, no. 2.
3	No. 2	do	Do.

three series. These water and voids data were then used in computing the proportion of each ingredient to be used in the strength-specimen mixtures. Every mixture in which the mortar was sufficient to fill the void spaces in the course aggregate was subjected to one slump test, and three 6 by 12-inch cylinders and one 6 by 8 by 30-inch beam were made. Every point on all strength curves represents the average of 3 breaks in either compression or flexure.

RESULTS OBTAINED IN SECOND GROUP OF TESTS

Table 11 is a summary of the data from this group of tests, with the exception of the densities from which the concrete-voids curves were drawn. These data are represented by the points on the concrete-voids curves.

Table 12 shows the results of slump tests for each value of b_s in each series.

Table 13 shows the amount of water in addition to that required for the mortar that is required by the coarse aggregate at basic water content for the two types of coarse aggregate used.

Table 14 shows the water and total voids per unit volume of concrete at basic water content for the different values of b_s in each set.

Table 15 contains the mix proportions by weight for all mixtures used in strength specimens in each set.

Figures 10, 11, and 12 show the concrete-voids curves for all mixtures in each series of tests. In figure 10 the curve for the mixture with $b_s = 0.70$ and in figure 11 the curve for the mixture with $b_s = 0.803$ represent those mixtures in which the mortar was not sufficient to fill the void spaces in the coarse aggregate.

Figures 13 and 14 show the relation between the water-cement ratio and the compressive and flexural strengths of the concrete.

TABLE 12.—*Slump of concrete for each mixture in each series*

[$a/c = 2.576$; $w = 1.10$ relative]

b_s	Series 1	Series 2	Series 3
	Inches	*Inches*	*Inches*
0.0	4.5	2	5
.1	4	2.5	6
.2	4	2.5	4
.3	4.5	2.5	5
.4	4.5	2	4
.5	5	3	5.5
.6	3.5	1	5.5
.7		2.5	5.5
Average	4.5	2	5

TABLE 11.—*Summary of data from second group of tests*

	$\frac{a}{c}$	b_s	Relative water content	Data from concrete-voids determinations [1]					Data from strength specimens [2]																$\frac{W_c}{c}$	Gallons of water per sack of cement	Sacks of cement per cubic yard of concrete	$\frac{c}{V_a+c}$	Ratio of compressive to flexural strength
									Cylinders								Beams												
				Volume of batch	Voids: Water	Voids: Air	Voids: Total	Density	Volume of batch	Voids: Water	Voids: Air	Voids: Total	Density	Compressive strength	Average of individual percentage variations from arithmetic mean	Maximum spread in strength	Volume of batch	Voids: Water	Voids: Air	Voids: Total	Density	Flexural strength	Average of individual percentage variations from arithmetic mean	Maximum spread in strength					
				Cu. ft.					*Cu. ft.*					*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Cu. ft.*					*Lbs. per sq. in.*		*Lbs. per sq. in.*					
Series 1	2.576	0.0	1.10	0.308	0.321	0.050	0.371	0.629	0.304	0.325	0.037	0.362	0.638	5,290	1.0	134	1.223	0.315	0.051	0.366	0.634	690	10.1	201	1.82	6.33	10.39	0.330	7.67
	2.576	.1	1.10	.295	.303	.038	.341	.659	.292	.306	.030	.336	.664	4,597	2.5	343	1.213	.294	.066	.360	.640	706	4.3	83	1.83	6.35	9.73	.333	6.52
	2.576	.2	1.10	.2855	.283	.036	.319	.681	.281	.288	.020	.308	.692	4,229	3.0	365	1.148	.282	.040	.322	.678	647	15.9	239	1.86	6.47	8.98	.334	6.55
	2.576	.3	1.10	.274	.261	.028	.289	.711	.271	.264	.017	.281	.719	3,992	1.7	173	1.103	.260	.035	.295	.705	657	5.0	76	1.88	6.53	8.15	.333	6.08
	2.576	.4	1.10	.264	.239	.0225	.2615	.7385	.260	.242	.009	.251	.749	3,261	2.7	227	1.058	.238	.026	.264	.736	679	2.7	48	1.91	6.73	7.27	.333	4.80
	2.576	.5	1.10	.2545	.215	.0185	.2335	.7665	.252	.216	.011	.227	.773	3,067	0.5	36	1.018	.215	.018	.233	.767	676	.8	13	2.01	6.99	6.25	.322	4.54
	2.576	.6	1.10	.2435	.186	.012	.198	.802	.243	.187	.008	.195	.805	2,299	9.9	580	.986	.184	.024	.208	.792	606	3.0	42	2.09	7.25	5.20	.314	3.79
Series 2	2.576	.000	1.10	.3055	.316	.0615	.3775	.6225	.301	.312	.062	.374	.626	2,820	8.4	612	1.228	.309	.071	.380	.620	759	1.4	30	1.78	6.11	10.27	.390	3.72
	2.576	.102	1.10	.295	.298	.0555	.3535	.6465	.291	.302	.044	.316	.654	3,312	16.5	1,530	1.189	.296	.062	.358	.642	605	1.1	18	1.81	6.34	9.62	.322	5.47
	2.576	.203	1.10	.286	.278	.0525	.3305	.6695	.283	.281	.043	.324	.676	3,787	2.5	239	1.159	.275	.063	.338	.662	621	5.9	92	1.88	6.46	8.80	.317	6.10
	2.576	.304	1.10	.2715	.253	.0395	.2925	.7075	.271	.254	.037	.291	.709	3,491	4.3	391	1.091	.252	.043	.295	.705	642	5.1	92	1.85	6.36	8.06	.321	5.41
	2.576	.404	1.10	.263	.232	.0355	.2675	.7325	.261	.234	.027	.261	.739	3,418	4.3	364	1.018	.234	.030	.264	.736	638	6.5	120	1.92	6.60	7.17	.319	5.36
	2.576	.505	1.10	.252	.2085	.0255	.234	.766	.252	.209	.023	.232	.768	3,092	2.2	158	1.025	.206	.041	.247	.753	532	6.2	81	1.98	6.85	6.20	.313	5.81
	2.576	.605	1.10	.246	.1815	.0205	.202	.798	.242	.182	.017	.199	.801	2,875	2.8	199	.991	.178	.040	.218	.782	457	2.4	29	2.07	7.13	5.17	.308	6.29
	2.576	.704	1.10	.2355	.162	.0115	.1735	.8265	.236	.161	.014	.175	.825	1,721	3.7	179	.944	.161	.014	.175	.825	348	4.1	43	2.10	8.25	3.91	.278	4.95
Series 3	2.576	.0	1.10	.308	.321	.050	.371	.629	.305	.325	.038	.363	.637	4,606	4.3	579	1.254	.318	.059	.377	.623	670	5.9	111	1.83	6.34	10.35	.330	6.87
	2.576	.1	1.10	.296	.3035	.0415	.345	.655	.295	.305	.037	.342	.658	4,227	2.5	281	1.203	.299	.056	.355	.645	597	3.7	55	1.81	6.10	9.62	.326	7.08
	2.576	.2	1.10	.285	.2805	.0375	.318	.682	.284	.282	.032	.314	.686	3,905	6.5	630	1.585	.276	.052	.328	.672	583	2.7	38	1.84	6.10	8.89	.327	6.70
	2.576	.3	1.10	.274	.261	.028	.289	.711	.275	.261	.030	.291	.709	3,738	3.0	282	1.122	.255	.042	.297	.703	520	4.9	61	1.89	6.55	8.03	.322	7.19
	2.576	.4	1.10	.264	.2375	.0245	.262	.738	.264	.238	.023	.261	.739	3,465	1.4	112	1.043	.240	.013	.253	.747	505	2.9	32	1.93	6.70	7.17	.321	6.86
	2.576	.5	1.10	.258	.221	.021	.242	.758	.258	.221	.021	.242	.758	2,586	2.0	152	1.027	.222	.016	.238	.762	561	1.9	26	2.10	7.30	6.13	.304	4.61
	2.576	.6	1.10	.245	.1915	.012	.2035	.7965	.246	.191	.014	.205	.795	2,249	1.7	106	.979	.194	.007	.201	.799	459	.1	2	2.17	7.52	5.13	.301	4.90
	2.576	.7	1.10	.242	.1815	.0095	.191	.809	.240	.183	.001	.184	.816	1,017	1.9	136	.963	.183	.004	.187	.813	305	.8	6	2.70	9.38	3.91	.270	3.33
Average															1.0								1.2						5.68

---

[1] Taken from concrete-voids curves.

[2] Each value is the average of 3 values except beam densities and voids which are based on 1 determination each.

Table 13.—*Calculations to determine the amount of water needed to lubricate the coarse aggregate in concrete mixtures at basic water content*[1]

1 b_s	2 Density	3 W_c	4 V_c	5 Air	6 Volume of dry materials plus absorption	7 Batch volume	8 Volume water	9 Volume dry coarse aggregate	10 Volume sand and cement	11 Water required for mortar	12 Water required for coarse aggregate	13 Water per cubic foot of coarse aggregate, by solid volume
					Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Gallons*
GRAVEL												
0.0000	0.6290	0.2870	0.3710	0.0840	0.1901	0.3022	0.0867	0.0000	0.1901	0.0867	0.0000	0.000
.1017	.6515	.2710	.3485	.0775	.1907	.2927	.0793	.0194	.1711	.0780	.0013	.501
.2032	.6770	.2530	.3230	.0700	.1914	.2827	.0715	.0388	.1521	.0693	.0022	.424
.3040	.7105	.2300	.2895	.0595	.1921	.2704	.0622	.0582	.1331	.0607	.0015	.193
.4045	.7380	.2110	.2620	.0510	.1927	.2611	.0551	.0776	.1141	.0520	.0031	.299
.5054	.7695	.1895	.2305	.0410	.1934	.2513	.0476	.0970	.0951	.0434	.0042	.324
.6047	.8045	.1650	.1955	.0305	.1939	.2410	.0398	.1163	.0761	.0347	.0051	.327
.7039	.8300	.1470	.1700	.0230	.1946	.2345	.0344	.1357	.0571	.0261	.0083	.457
Average												.361
CRUSHED LIMESTONE												
0.0000	.6420	.2920	.3580	.0660	.1940	.3021	.0881	.0000	.1940	.0881	.0000	.000
.1000	.6640	.2750	.3360	.0610	.1942	.2926	.0805	.0194	.1746	.0793	.0011	.428
.2000	.6890	.2570	.3110	.0540	.1944	.2825	.0726	.0388	.1552	.0726	.0021	.408
.3000	.7145	.2370	.2855	.0485	.1946	.2725	.0646	.0582	.1358	.0617	.0028	.362
.4000	.7430	.2170	.2570	.0400	.1948	.2625	.0568	.0776	.1664	.0529	.0040	.384
.5000	.7725	.1950	.2275	.0325	.1951	.2526	.0483	.0970	.0970	.0440	.0052	.400
.6000	.8070	.1690	.1930	.0240	.1953	.2422	.0409	.1164	.0776	.0352	.0057	.364
Average												.394

[1] Water to lubricate coarse aggregate with b_s of 0.00 is not included in the averages shown.

The values for the water required for mortar shown in column 11 for those mixtures containing coarse aggregate are in the same ratio to the corresponding values for volume of sand and cement shown in column 10 as the ratios between similar values (in same column), for the mixture containing no coarse aggregate. The water value for the mortar mixture, from which the water values for the mortar in the concrete mixtures are computed, is obtained from the mortar-voids curve. The water required for the coarse aggregate for each mixture shown in column 12 is the difference between the corresponding water values in columns 8 and 11.

Table 14.—*Water and total voids per unit volume of concrete at basic water content for different values of* b_s

Series 1			Series 2			Series 3		
b_s	Water voids	Total voids	b_s	Water voids	Total voids	b_s	Water voids	Total voids
	Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
0.0	0.292	0.358	0.00	0.287	0.371	0.0	0.292	0.358
.1	.275	.336	.102	.271	.3485	.1	.276	.336
.2	.257	.311	.203	.253	.323	.2	.255	.308
.3	.237	.2855	.304	.230	.2895	.3	.2375	.284
.4	.217	.257	.404	.211	.262	.4	.216	.255
.5	.195	.2275	.505	.1895	.2305	.5	.201	.235
.6	.169	.193	.605	.165	.1955	.6	.174	.1975
			.704	.147	.170	.7	.165	.185

Table 15.—*Proportions by weight for all mixtures used in strength specimens in each series*

Series 1				Series 2				Series 3			
b_s	Proportions by weight			b_s	Proportions by weight			b_s	Proportions by weight		
	Cement	Fine aggregate	Coarse aggregate		Cement	Fine aggregate	Coarse aggregate		Cement	Fine aggregate	Coarse aggregate
0.0	1.00	2.09	0.00	0.000	1.00	2.08	0.00	0.0	1.00	2.09	0.00
.1	1.00	2.09	.34	.102	1.00	2.08	.32	.1	1.00	2.09	.32
.2	1.00	2.09	.76	.203	1.00	2.08	.73	.2	1.00	2.09	.72
.3	1.00	2.09	1.31	.304	1.00	2.08	1.25	.3	1.00	2.09	1.24
.4	1.00	2.09	2.04	.404	1.00	2.08	1.95	.4	1.00	2.09	1.93
.5	1.00	2.09	3.06	.505	1.00	2.08	2.92	.5	1.00	2.09	2.89
.6	1.00	2.09	4.59	.605	1.00	2.08	4.39	.6	1.00	2.09	4.33
				.704	1.00	2.08	6.81	.7	1.00	2.09	6.71

Figures 15 and 16 show the relation between the values of b_s and the compressive and flexural strength of the concrete.

Figure 17 shows photographs of the slumped concrete for each mixture and the beam breaks with the exposed particles of coarse aggregate painted.

RESULTS OF SECOND GROUP OF TESTS DISCUSSED

The two outstanding results shown in the first group of tests are repeated in these tests. They are as follows:

For a particular value of $\frac{a}{c}$ a relation exists between the values of b_s and the points of basic water content. The same relation likewise exists between the values of b_s and the points of other relative water contents (1.10 relative in these tests), which are computed from the basic. This relation is shown in figures 10, 11, and 12. In each of these figures the point of basic and the point of 1.10 relative water content on each b_s curve fall on lines that are approximately straight.

For a particular relative water content, 1.10 in these tests, the slump of every concrete mixture composed of the same kinds of materials is nearly constant regardless of the value of b_s for the mixture. The results of the slump test for each mixture in each series are shown in table 12. Figure 17 shows the slumped concrete for all mixtures in each series. The consistency of the slump-relative water relation is demonstrated by the fact that in each series the slump of the mixture containing no coarse aggregate is approximately the same as the slump of the mixture containing the maximum amount of coarse aggregate.

Other interesting results shown by these tests follow:

The point of basic water content may be different for every different combination of materials. For a given value of $\frac{a}{c}$ the amount of water and the resulting voids decrease as b_s increases. This is shown in table 14 and in figures 10, 11, and 12. The amount of water required to give maximum density to combinations of different materials having the same values of $\frac{a}{c}$ and b_s may vary for different brands and gradations of cement and for different kinds and gradations of fine and coarse

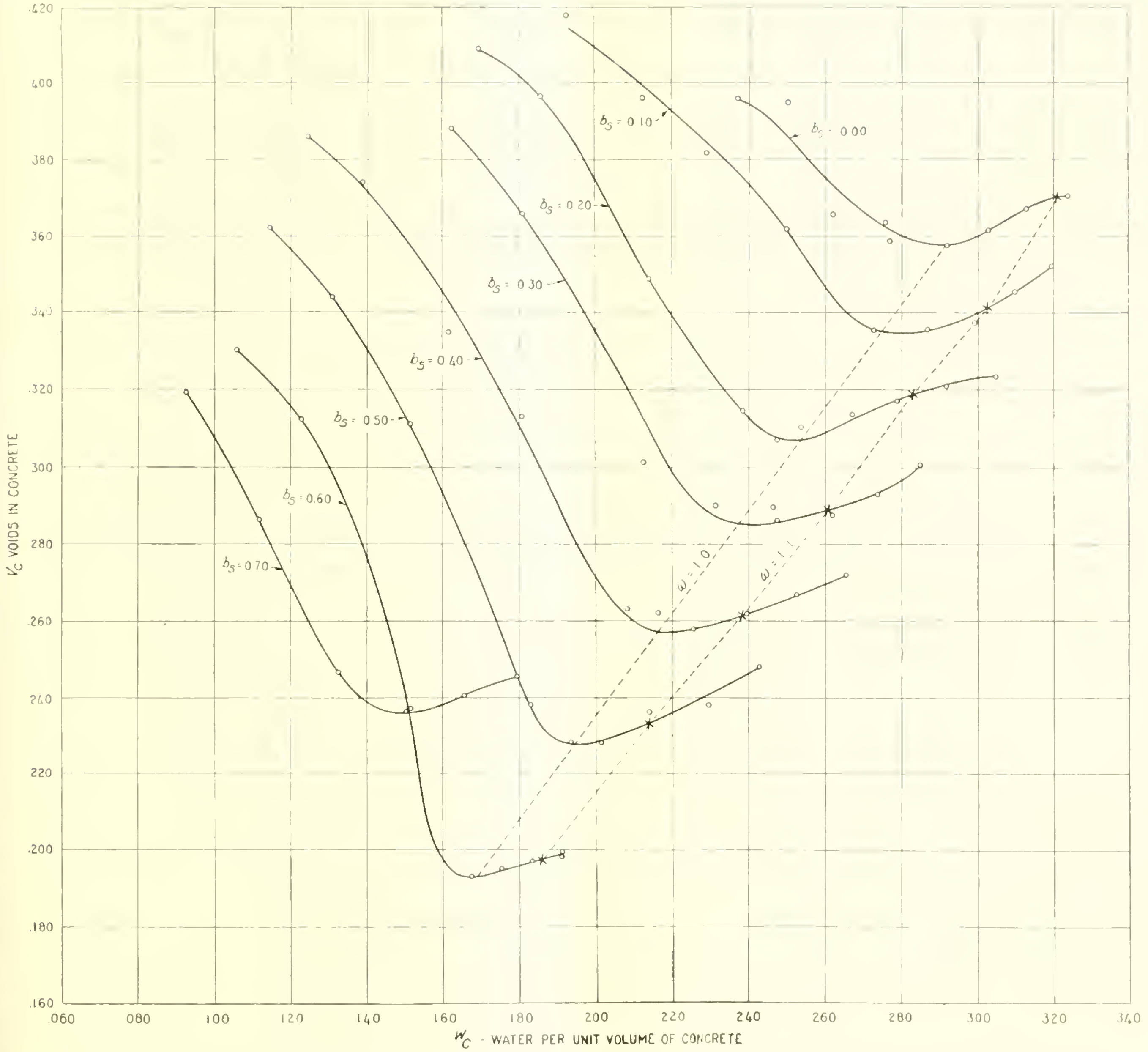

FIGURE 10.—CONCRETE-VOIDS CURVES FOR FIRST SERIES (VARYING VALUES OF b_s AND CONSTANT VALUE OF $\frac{a}{c}=2.576$).

aggregate. This is shown in table 14. The water and the total voids vary for similar proportions in the different series.

The concrete mixtures having maximum density as placed in the mold in this test contained both water and air voids.

The well-known relation between the water-cement ratio and the strength of concrete both in compression and flexure is shown in figures 13 and 14. The relationship does not approach a straight line as closely as in the first series of tests.

No relation is apparent between densities and strengths of different concrete mixtures. However, table 11 shows that the density increases and the strength decreases as the value of b_s increases for each series.

Mixtures with the same relative water content and the same values of $\frac{a}{c}$ and b_s may vary considerably in slump, depending on the characteristics of the ingredients. Table 12 shows an average slump of 5 inches for series 3 and 2 inches for series 2. The same kind of fine and coarse aggregate was used in both series, but the brand of cement was different. There is also a difference in the average slumps of series 1 and 3 of ½ inch. Here the only variation in the kind of materials used was in the coarse aggregate. Series 1 had an average slump of 4½ inches, against a slump of 2 inches for series 2. Different brands of cement and different kinds of coarse aggregate were used in these series. It appears from this test that the characteristics of the cement play an important part in affecting the slump or workability at any particular relative water content. The influence of the fine aggregate or the combination of fine aggregate and cement on the slump is not shown since the same kind of fine aggregate was used in all series.

In these tests the compressive and flexural strength of concrete decreased as the value of b_s increased. This is shown in figures 15 and 16. There are exceptions to this trend, however. It is believed that these exceptions are due to the inconsistencies inherent in

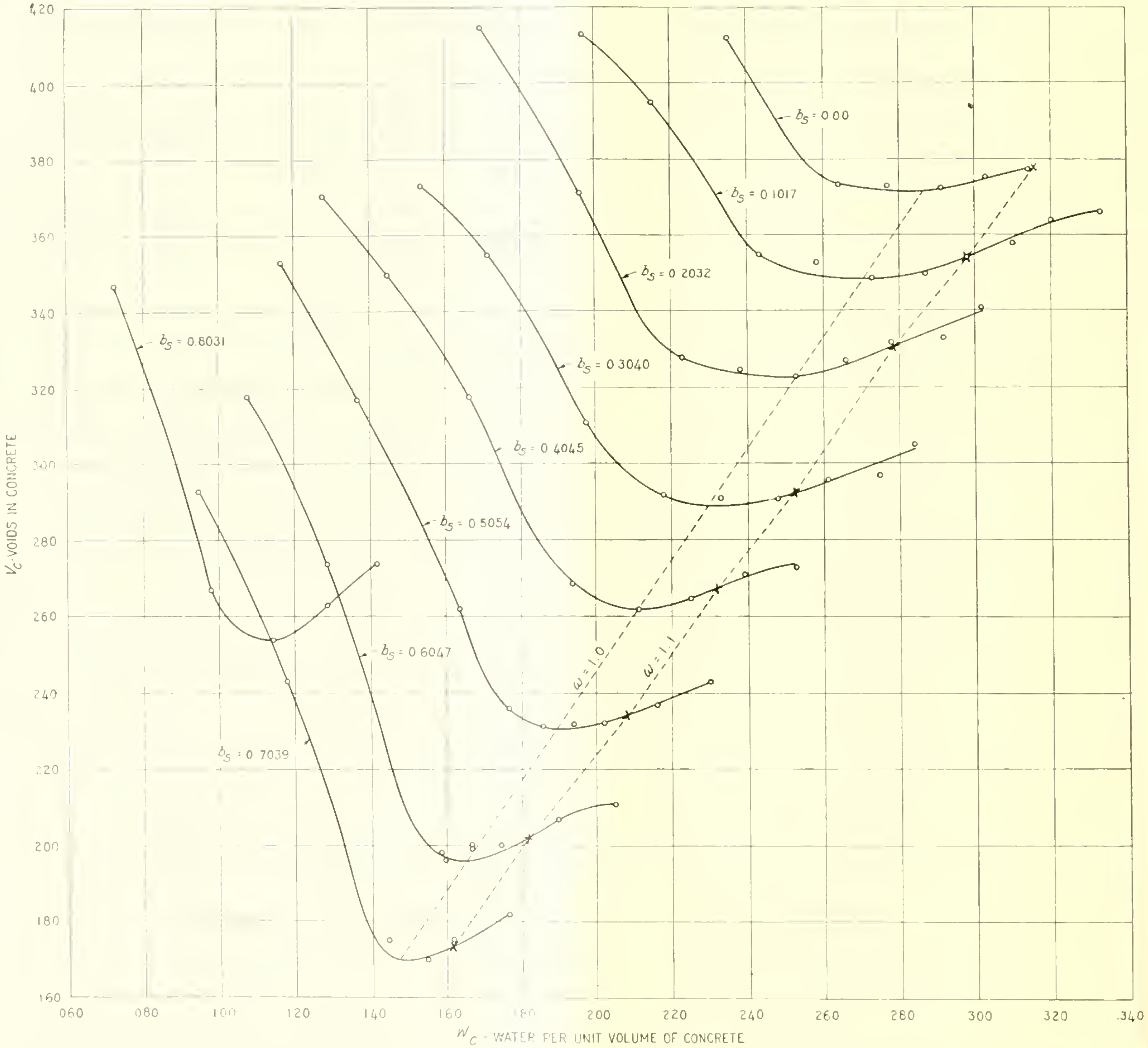

Figure 11.—Concrete-Voids Curves for Second Series (Varying Values of b_s and Constant Value of $\frac{a}{c}$=2.576)

testing work. As an example, figure 15 shows low compressive strengths for mixtures of series 2 with values of b_s of 0.00 and 0.10. Table 11 shows that for these particular mixtures the maximum spread in the strengths and the average of the variations from the mean are excessive. One of the cylinders with a value of b_s of 0.10 had a strength of 4,033 pounds. A poor cylinder in the group brought the average down. With the exception of these two mixtures the strength-b_s relation is more consistent for the cylinders than for the beams. The corresponding values of $\frac{W_c}{c}$ for all values of b_s are shown in table 11.

The relation between the kind of cement used and the strength of the concrete is shown in table 11. The slump of the concrete in series 1 and 3 was 4½ and 5 inches, respectively. The slump of the concrete in series 2 was 2 inches. Had series 1 and 3 been made with a relative water content such as to give a 2-inch slump the strengths for these series would doubtless be much higher and would be considerably in excess of the strengths of corresponding mixtures in series 2. The same aggregates but different brands of cement were used in series 2 and 3. The same brand of cement but different coarse aggregates were used in series 1 and 3. Had these brands of cement been used with other kinds of fine aggregate the resulting slumps and strengths might have been still different.

The proportions by weight of all mixtures are shown in table 15. The proportions of mixtures having similar values of b_s differ somewhat in the different series due to differences in the specific gravities of the materials.

In these tests no definite relation was found between the compressive and flexural strengths of specimens composed of the same mixtures. Table 11 shows the

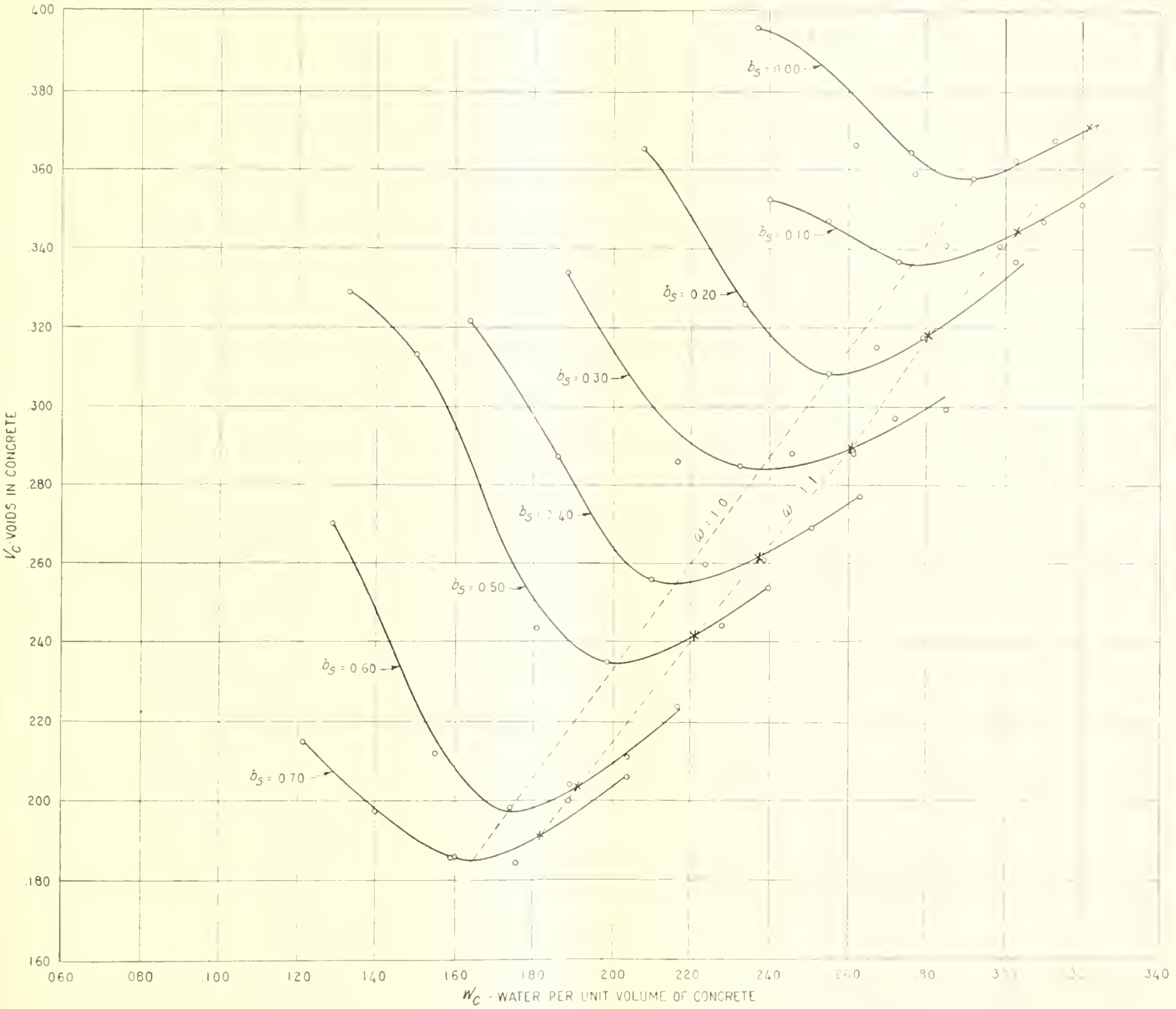

FIGURE 12.—CONCRETE-VOIDS CURVES FOR THIRD SERIES (VARYING VALUES OF b_s AND CONSTANT VALUE OF $\frac{a}{c}$ = 2.576)

ratio of compressive to flexural strength for all mixtures. This ratio varies from 3.33 to 7.70 with an average for all mixtures of 5.68.

The amount of water required to give maximum density to a particular mortar is not the same as that required to give maximum density to the concrete when coarse aggregate is added to this mortar. Additional water is required in the concrete by the coarse aggregate. Table 13 has been prepared from the concrete-voids curves for series 1 and 2 to show this relation. The last column shows the amount of water (in addition to that required for the mortar) in gallons per cubic foot of solid volume of coarse aggregate required to give maximum density to the concrete. The values are fairly consistent for all values of b_s for each of the two types of coarse aggregate used. The variations in the values are, no doubt, due to irregularities in the curves from which they were computed. These data indicate the necessity for making density determinations on the concrete mixture rather than on the mortar in the concrete.

CONCLUSIONS

The results of these tests corroborate general knowledge concerning the behavior of concrete mixtures. They shed new light and help to rationalize the complex relations existing in such mixtures. The following conclusions are based on these results:

1. For the range of water contents equal to or greater than basic, density determinations and the concrete voids curves resulting from them offer a definite basis for determining, for a given combination of particular materials:

The amount of water required to give maximum density and maximum strength. Expressing amounts of water in terms of this basic water content establishes a definite unit of measurement for designating the water required for any degree of workability.

The total voids for each relative water content. These data are necessary to accurately compute the solid volume of each ingredient required to produce a unit volume of concrete and the resulting water-cement ratio.

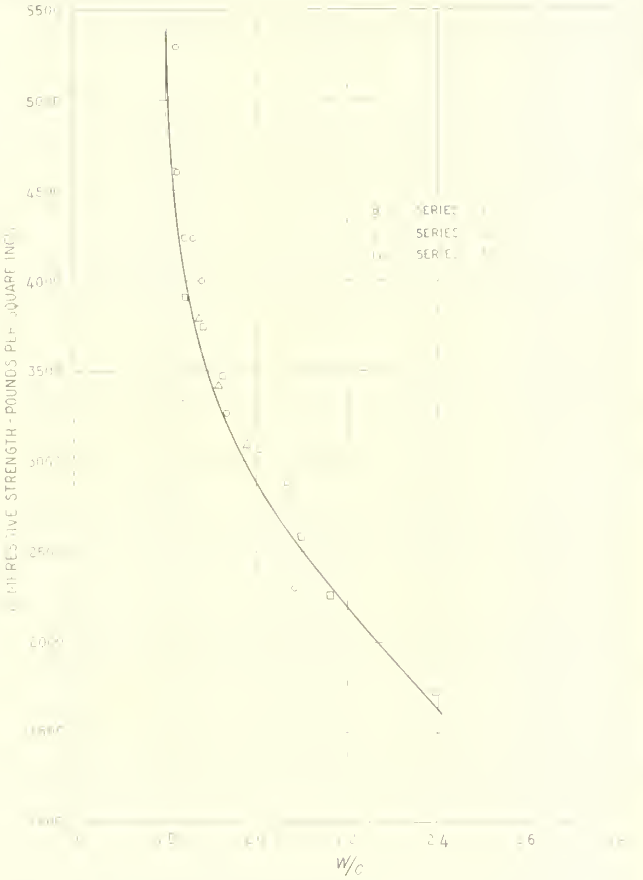

Figure 13.—Effect of Water-Cement Ratio on Compressive Strength.

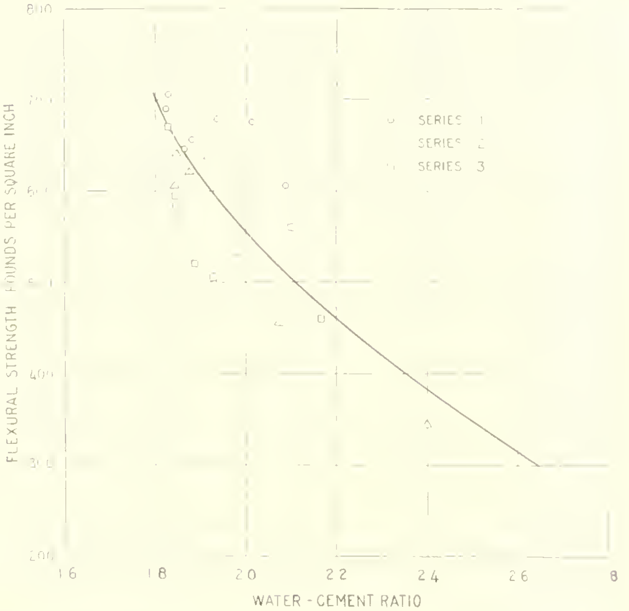

Figure 14.—Effect of Water-Cement Ratio on Flexural Strength.

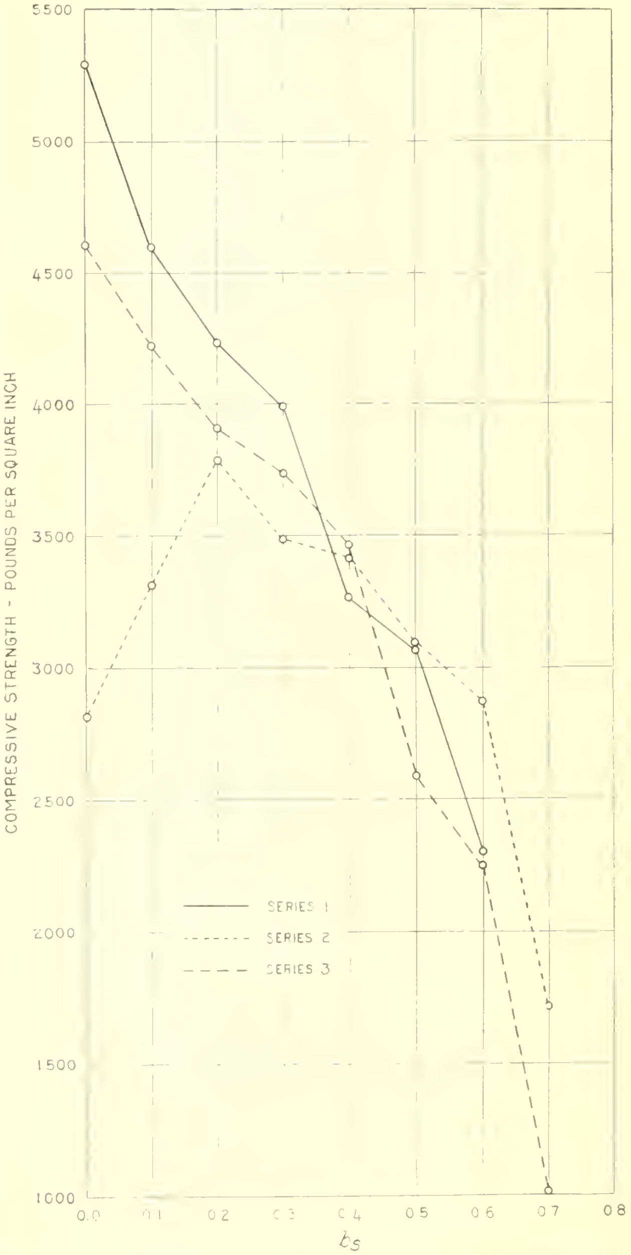

Figure 15.—Effect of Variation in Coarse Aggregate Content on Compressive Strength.

The effect of different kinds of ingredients on the amount of water required for maximum density and for different degrees of workability.

2. The density of the concrete should be determined rather than that of the mortar.

3. The amount of water required to give maximum density or to give a particular degree of workability may be different for every different combination of materials. To specify a fixed amount of water per unit volume of cement or concrete regardless of the proportions and characteristics of the ingredients is not sound.

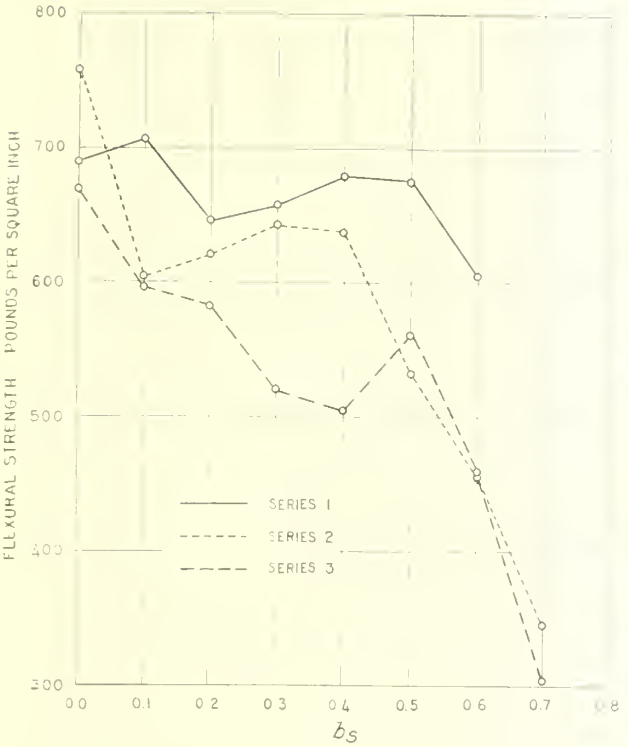

Figure 16.—Effect of Variation in Coarse Aggregate Content on Flexural Strength.

4. The strengths of different concrete mixtures composed of different kinds of materials apparently bear no relationship to their respective densities. The strength of a particular concrete mixture, however, can be expected to vary directly with its density, when the water content is equal to or greater than basic.

5. The symbols $\frac{a}{c}$ and b_s offer a definite basis for designating proportions. With these designations the proportions of the cement and aggregates remain constant, and do not change with changes in the relative water content, as would be the case were the proportions of these ingredients expressed as the ratios of their respective volumes to a unit volume of concrete. The method used is particularly convenient in designating the basic proportions of cement and aggregates to which increments of water are added in making density determinations for the concrete-voids curves.

6. The strength of concrete varies directly with the water-cement ratio.

7. The slump of a concrete mixture depends largely on its relative water content. For the same relative water content and the same kinds of ingredients, the slump will be about the same regardless of the proportions of cement, fine and coarse aggregate used in the mixture.

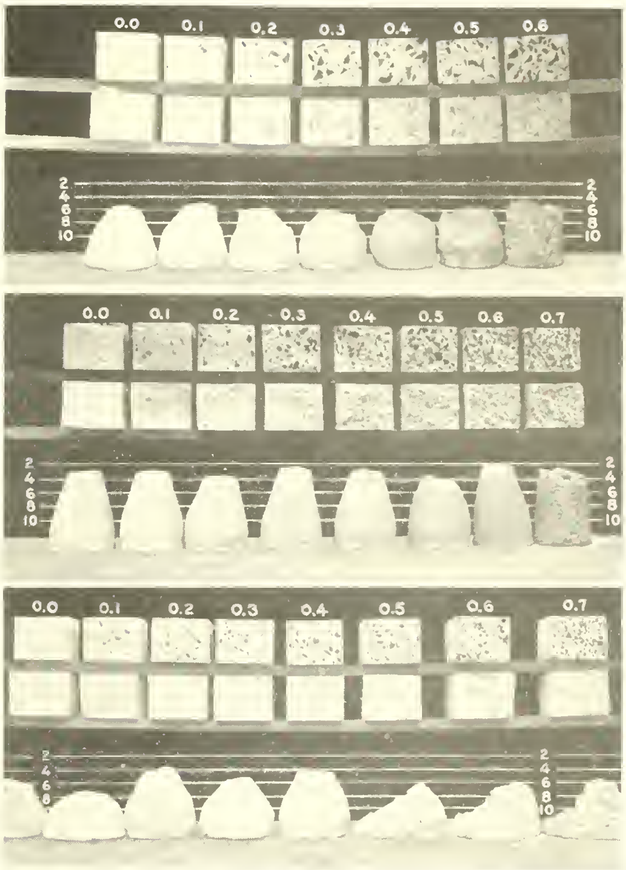

Figure 17.—Slump Test Specimens and Corresponding Beam Breaks for Test Series 1, 2, and 3 in the Order Named from Top to Bottom. Values of b are Shown Above Beam Specimens. Coarse Aggregate has been Painted on Upper Beam Break in Each Case.

8. A definite relationship evidently exists between the basic and relative water contents and the values of b_s for any particular value of $\frac{a}{c}$.

The results in the first group of tests indicate that a relation exists between the basic water content and the values of $\frac{a}{c}$ for any particular value of b_s. The range in the values of $\frac{a}{c}$ in this test, however, was not great, and the resulting values of W_r and V_r for each value of $\frac{a}{c}$ for this water content were rather close together. The direction that this relation will take, that is, whether the values of W_r and V_r will increase or decrease as the value of $\frac{a}{c}$ increases can be expected to be regulated by the characteristics of the sand and cement used, and by the particular range in the values of $\frac{a}{c}$ considered.

MECHANICAL ANALYSIS OF PORTLAND CEMENT BY THE HYDROMETER METHOD

BY THE DIVISION OF TESTS, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by **E. A. Willis**, Assistant Highway Engineer, and **C. M. Johnston**, Junior Civil Engineer

THE hydrometer method of making a mechanical analysis of soils as described in the report "Procedures for Testing Soils for the Determination of the Subgrade Soil Constants", PUBLIC ROADS, volume 12, no. 8, October 1931, is adaptable, with few modifications, to the analysis of any fine-grained material. The chief advantages of the method are the ease and rapidity with which the analysis may be made, the flexibility of the procedure in respect to the number of grain sizes for which percentages may be determined and the suitability of the test for analyzing materials consisting of very small particles.

METHOD BASED ON STOKES' LAW

The previous article described a general method of analysis of fine-grained materials by the use of a hydrometer. A known weight of material is dispersed in a known amount of a suitable fluid. Settlement of particles takes place according to a physical law (Stokes' law), the larger particles settling most rapidly. Measurements of specific gravity are made with a hydrometer at various intervals of time. The specific gravity at any instant may be used to calculate the percentage of material remaining in suspension at that instant. A formula based on Stokes' law may be used to calculate the diameter of the largest particle in suspension at the time of measurement. Since it is approximately true that all larger particles have settled out of the liquid, the percentage of particles larger than the maximum size just referred to is easily determined.

The inherent errors of the method are described by R. C. Thoreen in an article entitled "Comments on the Hydrometer Method of Analysis", PUBLIC ROADS, volume 14, no. 6, August 1933. This report also describes a specially designed paddle and cup which are an improvement over those originally used.

This report describes in detail the procedure used in the mechanical analysis of portland cement. Since particles large enough to be retained on a 200-mesh sieve settle out of a liquid such as kerosene very rapidly, it was necessary to determine the percentage of larger particles by the ordinary screen analysis.

A series of sieves of square-mesh wire cloth, conforming to the standard specifications for sieves for testing purposes of the American Society for Testing Materials Serial Designation E-11, are used. The sieve numbers with their openings in millimeters are, resepectively: No. 10, 2.00 mm; no. 20, 0.84 mm; no. 40, 0.42 mm; no. 60, 0.25 mm; no. 140, 0.105 mm; and no. 200, 0.074 mm. A 50-gram sample of dried cement was used in the sieve analysis. Results of an analysis are shown in table 1.

The formulas necessary to compute the percentage of material in suspension in a liquid when the density is known and for computing the maximum diameter of particle in suspension are given below. The derivation of these formulas is discussed in the reports mentioned above.

TABLE 1.—*Results of sieve analysis of a 50-gram sample of cement*

Fraction				Total passing	
Passing sieve no. —	Retained sieve no. —	Weight	Amount	Amount	Diameter largest particle
		Grams	*Percent*	*Percent*	*Mm.*
10	20	0.000	0.0	100.0	0.840
20	40	0.000	0.0	100.0	0.420
40	60	0.000	0.0	100.0	0.250
60	140	0.150	0.3	99.7	0.105
140	200	1.850	3.7	96.0	0.074

For a 50-gram sample of cement dispersed in enough liquid to make 1,000 cubic centimeters of mixture,

$$D=\frac{G_k\left(1{,}000-\dfrac{\frac{50P}{100}}{G}\right)+\dfrac{50P}{100}}{1{,}000} \text{-------------}(1)$$

in which D = density of the mixture of cement and kerosene,

G_k = specific gravity of the kerosene at the temperature at which D was obtained,

G = specific gravity of cement,

and P = percentage of dispersed cement in suspension.

Solving equation (1) for P,

$$P=2{,}000\ G\left(\frac{D-G_k}{G-G_k}\right) \text{-----------------}(2)$$

$$d=\sqrt{\frac{30nL}{980(G-G_k)T}}=\sqrt{\frac{.0306nL}{(G-G_k)T}} \text{------}(3)$$

In this equation

d = maximum grain diameter in millimeters.

n = coefficient of viscosity of the suspending medium in poises. Varies with change in temperature of the suspending medium.

L = distance in centimeters through which particles settle in a given period of time.

T = time in minutes of sedimentation.

DETAILS OF TEST PROCEDURE DESCRIBED

A density type hydrometer is most satisfactory for the determination of the percentage of particles in suspension. In the investigations forming the basis of this report two hydrometers were used, since no single hydrometer covering the necessary range was available. The hydrometer should read from a minimum corresponding to the density of the kerosene used, to a maximum corresponding to the density of a suspension of 50 grams of cement per liter. For ordinary conditions a hydrometer having a range of 0.75 to 0.85 will be adequate.

A dispersing agent must be used in any mixture of cement with kerosene. Several dispersing agents in varying amounts were tried before it was found that 60 drops of oleic acid to the liter of kerosene was satisfactory. The oleic acid and kerosene should be mixed before the cement is added. It is important that the suspending medium be free of water and that the cement be thoroughly dry at the time of dispersion if flocculation is to be prevented.

The dispersion procedure is to fill the mixer cup to within 3 inches of the top with kerosene, add 60 drops of oleic acid, and mix for 1 minute. Remove cup, add 50 grams of oven-dried cement and add enough kerosene to bring the level to within 2 inches of the top, then stir in milk-shake machine for 15 minutes.

After dispersion, the mixture is transferred to a glass graduate and the dregs in the cup are washed into the graduate with more kerosene having the same constants and temperature as those used initially. Additional kerosene, having the same temperature as the constant temperature bath, is added until the mixture attains a volume of 1,000 cubic centimeters. The graduate containing the cement in suspension is then placed in the constant temperature bath. The liquid is stirred frequently with a glass rod to prevent settlement of the particles until the liquid attains the temperature of the bath. Then the graduate is removed and its contents thoroughly shaken for 1 minute. The palm of one hand is placed over the mouth of the graduate as a stopper and the graduate is given a slow end-for-end motion. At the conclusion of this shaking, the time is recorded, the graduate is placed in the bath and readings are taken on both the hydrometer and a thermometer in the liquid at the end of the following intervals in minutes: 1, 2, 5, 15, 30, 60, 250, and 1,440.

The hydrometer is always read at the top of the meniscus formed around its stem.

After the 5-minute reading is recorded, the hydrometer is very carefully removed from the liquid in such a manner as to cause no disturbance in it, is wiped clean and immersed in another graduate containing pure kerosene which is kept in the constant temperature bath. One minute before the time for another reading it is slowly and carefully replaced in the liquid being tested. This operation is performed to prevent cement particles from settling on the hydrometer and also to prevent the hydrometer from reducing the horizontal sectional area of the liquid through which the cement particles settle. The reading should not be taken until the hydrometer has come to rest.

Solution of the formulas requires information as to the specific gravity of the kerosene at the temperatures at which readings were taken, the coefficient of viscosity of the kerosene at the same temperatures, values of L for particle settlement, and the specific gravity of the cement. Specific gravity tests should be run on the kerosene at various temperatures and a curve plotted as shown in figure 1. Values corresponding to any temperatures can be taken from the chart. Similarly a chart for the viscosity-temperature relation is prepared, as shown in figure 2. Values for the viscosity coefficient were determined by means of an Engler viscosimeter using the formula suggested by the United States Bureau of Standards.[1]

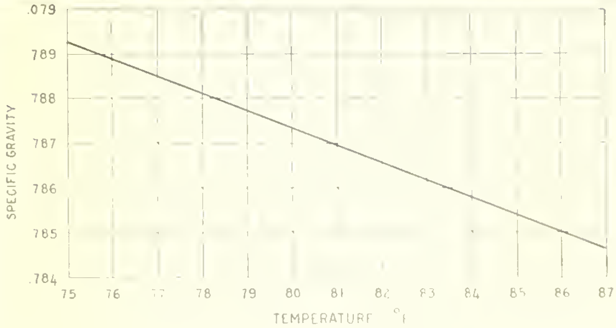

Figure 1.—Specific Gravity of Kerosene Used at Various Temperatures.

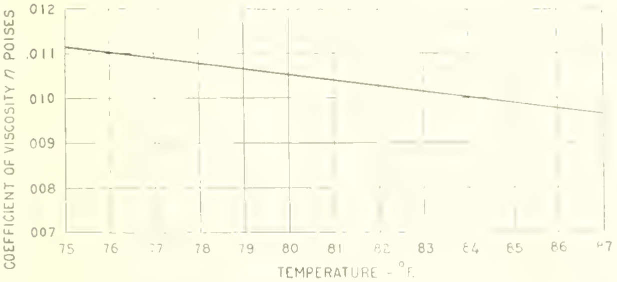

Figure 2.—Viscosity of Kerosene Used at Various Temperatures.

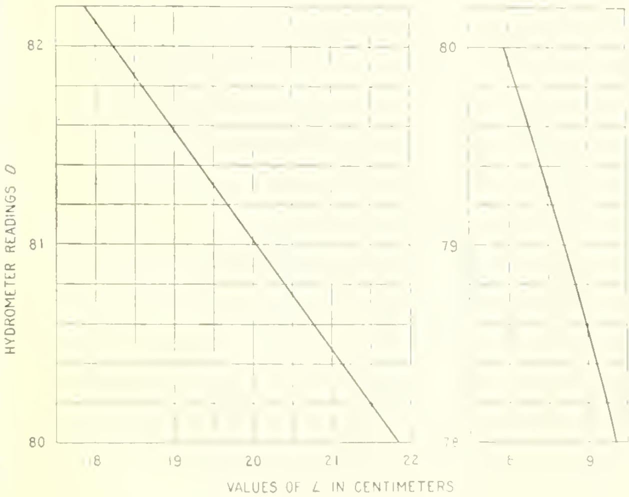

Figure 3.—Values of L Corresponding to Hydrometer Readings for Each Hydrometer Used.

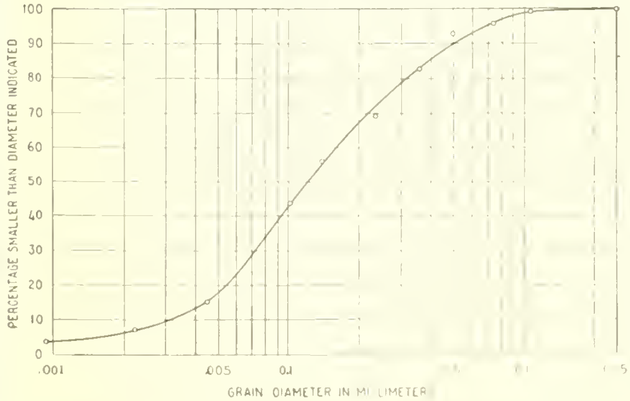

Figure 4.—Grain Size Accumulation Curve Based on Data of Tables 1 and 2.

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[1] See "The Redwood Viscosimeter", by Winslow H. Herschel, U.S. Bureau of Standards Technological Paper no. 210, p. 243.

Values of L, the distance through which the particles fall, were assumed to be the distance from the surface of the liquid to the center of volume of the hydrometer. Figure 3 shows such values for each hydrometer for various readings.

The specific gravity of the cement may be determined by the usual pycnometer method.

Table 2 shows the results of a series of hydrometer readings and the computations based on them.

As an example of the use of the formulas assume that it is desired to find the percentage, P, of cement in suspension after 2 minutes.

$$G=3.065,\text{ and }\frac{D-G_k}{G-G_k}=0.0136\text{ when }T=2$$

$$P=2{,}000\times 3.065\times 0.0136=83.42\text{ percent.}$$

Assume that it is desired to find the diameter of the largest particle in suspension after a 30-minute period of sedimentation. According to table 1, after a 30-minute period, the temperature was 77° F. Consequently, $G_k=0.7885$ and $n=0.01088$ poise. Since the hydrometer reading at this time was 0.8050 the distance L (fig. 3) equals 20.96 cm.

Solving equation 3 for d we obtain,

$$d=\sqrt{\frac{0.0306\times 0.01088\times 20.96}{2.2765\times 30}}$$

$$d=0.0101\text{ mm.}$$

TABLE 2.—*Tabulation of observations and computations*

[Sample No. 11,724 Specific gravity = G = 3.065]

T	°F	D	G_k	$D\text{-}G_k$	$G\text{-}G_k$	$\frac{D\text{-}G_k}{G\text{-}G_k}$	n	L	P	d
Min.					*G=3.065*		*Poises*	*Cm.*	*Pct.*	*mm.*
1	82	0.8210	0.7866	0.0344	2.2784	0.0151	0.01025	18.06	93	0.0499
2	81	.8180	.7870	.0310	2.2780	.0136	.01038	18.60	83	.0360
5	80	.8130	.7874	.0256	2.2776	.0112	.01050	19.51	69	.0235
15	78	.8090	.7881	.0209	2.2769	.0092	.01075	20.24	56	.0139
30	77	.8050	.7885	.0165	2.2765	.0072	.01088	20.96	44	.0101
60	77	.7940	.7885	.0055	2.2765	.0024	.01088	[1] 8.42	15	.00453
250	77	.7910	.7885	.0025	2.2765	.0011	.01088	8.64	7	.00225
1,440	77	.7895	.7885	.0010	2.2765	.0004	.01088	8.72	3	.00094

[1] The sudden change in values of L is due to the use of another hydrometer at this point.

The data in the last two columns of table 2 may be used to plot a grain-diameter accumulation curve as shown in figure 4 with the exception of the portion of the curve for diameters of over 0.05 millimeter. This portion of the curve is derived from the data of table 1. This curve is plotted on semilogarithmic paper.

OBSERVATIONS ON BULLDOZERS AND LARGE SCRAPERS IN GRADING WORK

BY THE DIVISION OF MANAGEMENT, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by **ANDREW P. ANDERSON**, Highway Engineer

THE use of large tractor-powered bulldozers as actual excavating units and the use of large-capacity scrapers are comparatively recent innovations in highway grading. From time to time, this type of equipment has been found in use on jobs on which production studies were being conducted by the Bureau of Public Roads and the data thus accumulated will be summarized and reviewed briefly.

The bulldozer has long been standard equipment on the dump or fill, but its use in the cut as a combined excavating and hauling unit has, until recently, been very limited. All available data, however, indicate that the bulldozer and the modified type frequently known as the "trail builder" are well adapted to moving common excavation where the hauls are comparatively short and down rather steep grades and the materials are, or can be made, loose enough to permit the rapid accumulation of a load. If the material is at all hard or solid, it should be loosened with a rooter or a scarifier, or by blasting. The bulldozer is entirely satisfactory only where the ground is loose enough to permit a load to be picked up within a length of 25 to 40 feet with the tractor moving at a speed of 2.0 to 2.5 feet per second. If the material is too hard or tight to permit a full load to be picked up in from 10 to 20 seconds, it should be loosened with a rooter or by scarifying or by blasting.

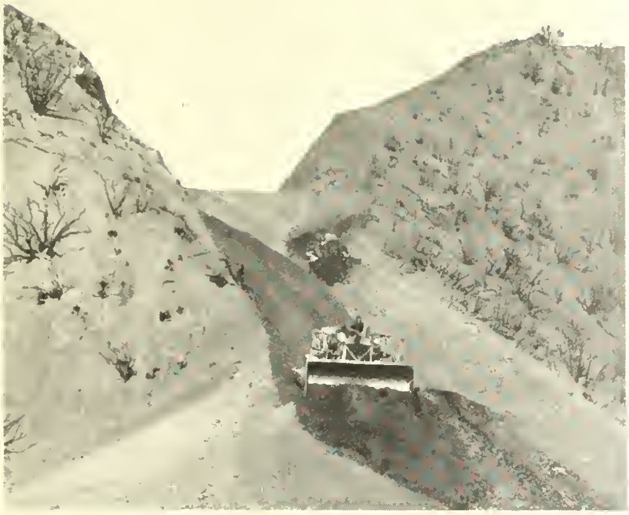
BULLDOZERS USED IN CONJUNCTION WITH POWER SHOVEL

The tractor-powered bulldozer has thus far found its widest use as an excavating unit in conjunction with the power shovel when operating in rather rough, broken country with a deep mantle of soil or deeply weathered and decomposed rocks and shales. The bulldozer has certain characteristics which appear to limit its profitable operation as an excavating implement to jobs having these general features. It is most effective in moving material down steep slopes. As the grade decreases the efficiency decreases very rapidly, and on an ascending grade the efficiency of transportation is very low.

Proper material is essential. The material must be naturally loose or at least sufficiently friable to permit rapid and direct accumulation after loosening. Hard rocks and very hard shales can rarely be shattered sufficiently for movement with a bulldozer.

A relatively short haul is the third requirement. The tendency of the materials to spill around the ends of the bulldozer blade usually makes long movements unprofitable. Unless the grade is very steep a large load at the start will soon dwindle to a small one. Where a large yardage is moved along one path a trough or trench is formed by spillage around the ends of the blade and soon becomes sufficient to reduce further spillage. This advantage of path movement on long hauls should be utilized as much as possible. Sometimes the spillage around the ends of the bulldozer blade can be reduced by working two bulldozers abreast with their blades only a few inches apart. Observations on a job where this was tried indicated that the yardage moved per trip by the two tractors was increased nearly 20 percent over that moved when working independently.

The bulldozer is particularly useful in conjunction with the power shovel. On steep ground the pioneer road work necessary for the shovel to reach the first



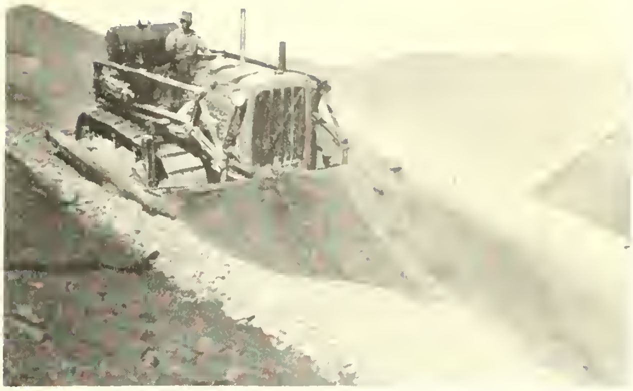
Cut Illustrated on Cover Page at an Advanced Stage of Construction.

lift of a deep cut can frequently be greatly reduced and sometimes entirely eliminated by having the bulldozer build up both an approach for the shovel and a hauling road for the trucks or wagons. Often a cut which would normally be made in two or three lifts may be reduced in this way by one lift and better hauling roads provided because of the adaptability of the bulldozer to the conditions. With the bulldozer this can generally be done with the movement of only pay materials, whereas the older method frequently requires the movement of considerable quantities of nonpay materials in the construction of approach roads in zigzags up the steep slopes.

The bulldozer has been found effective in sidehill work. Work is usually begun along the upper line of slope stakes and the material moved ahead and to the side as the conditions may require. So long as the material is loose or can be loosened and the haul distance is short enough to maintain a rather steep grade along which to move the material, good production rates can be maintained.

The best operating speed at which to haul the loads is still largely a matter of opinion. The general practice is to work at about the maximum speed possible without obviously straining the power unit. This practice may be entirely correct for many or possibly most cases. It was noted during recent job studies that in moving loose, noncohesive material down steep grades the amount of material which would push or flow in front of the blade was much larger at a speed of 2 feet per second or less than for a speed of 3.5 feet per second. There appears to be some optimum speed which will yield the greatest production, at least when moving loose, noncohesive materials down steep grades. However, no definite data are available as to what this most productive speed is or how it may vary with different materials and on different slopes.

Opening a cut with the bulldozer in ground as described above is comparatively simple, although on very steep ground considerable skill and ingenuity are required in maneuvering the bulldozer in its climb to the very top of the cut. Once this point has been reached the bulldozer begins to dig along the highest point of the upper slope line. The excavated material is pushed ahead toward the fill. If the ground slope is steeper than the tractor can readily climb in reverse, the material is simply pushed clear of the immediate excavation and allowed to accumulate along the line of the hauling road until a runway is provided with flat enough grade to permit the bulldozer to return readily in reverse after delivery of its loads to the fill. If the ground slope is already flat enough for the tractor to return fairly easily, every load is carried to the fill. In both cases the slope of the hauling road for the bulldozer is kept as steep as possible because, within limits, the steeper the grade the larger the load which can be carried to the fill.



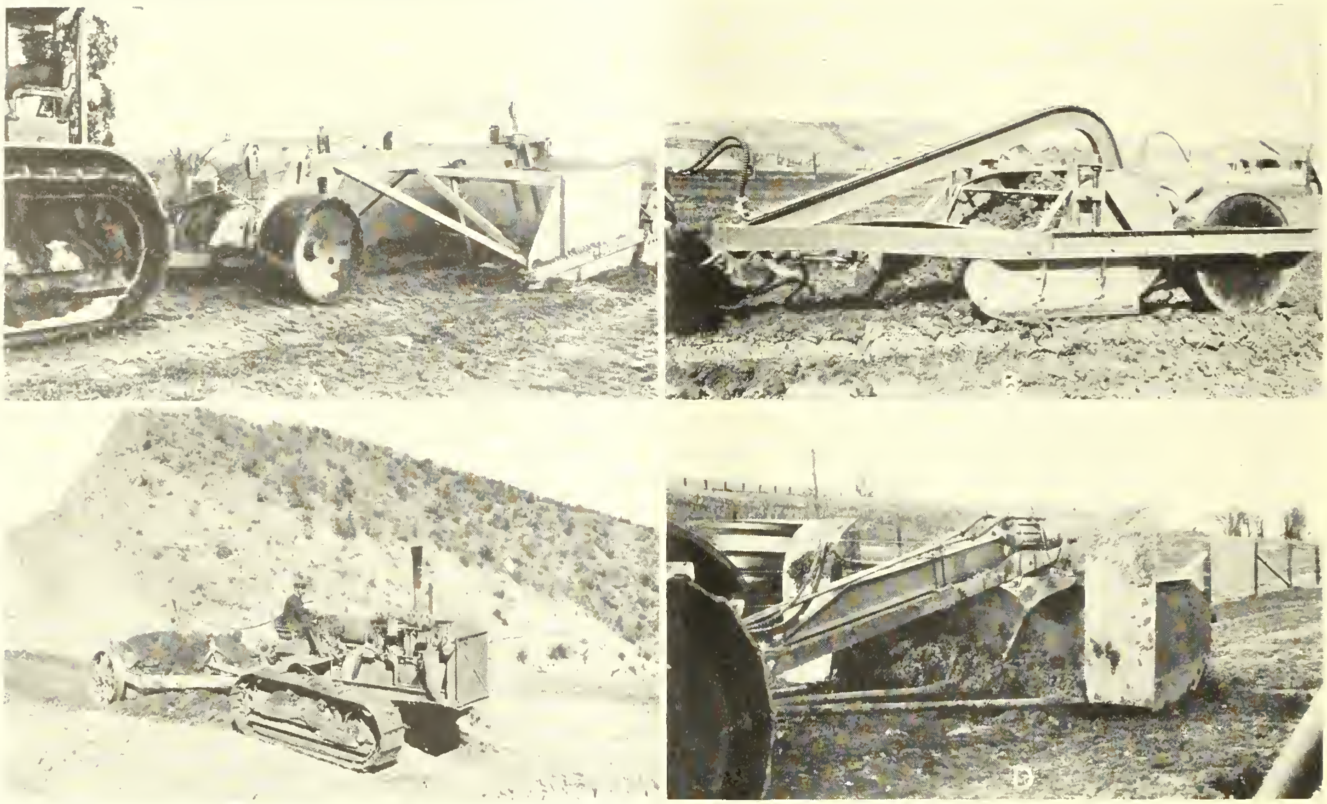
The Largest Loads are Moved on Steep Grades.

As the work progresses the runway is widened to finally include the full width of the cut. In a wide cut three or four bulldozers can sometimes be operated without interference, and even more if the haul is in both directions. If the material becomes too hard for easy loading, a heavy scarifier or rooter drawn by a powerful tractor may be used to loosen it. If the ground becomes still harder, blasting should be resorted to. The harder rocks and shale, however, can seldom be reduced sufficiently to make the use of the bulldozer profitable. When rock or ground of this nature is reached further work is left to the power shovel.

The steeper the grade the larger the load which can be carried to the fill and the longer the haul on which the bulldozer can be used profitably. The only limit to the grade is the ability of the tractor to climb on the return. A large crawler tractor in good condition and equipped with a 10-foot standard bulldozer has been observed to climb a grade as steep as 50 percent.

Field observations indicate that the average load which can be carried from cut to fill under ordinary field conditions varies with the length and shape of the blade, the grade along which the load is moved, and the character of the material. The observations are confirmed to some extent by the data of table 1. During recent studies of the use of four bulldozers in moving considerable yardages it was found that loads frequently fluctuated as much as 100 percent. For a certain bulldozer the smallest loads would be about 2 cubic yards, and the largest loads would be about 4 cubic yards.

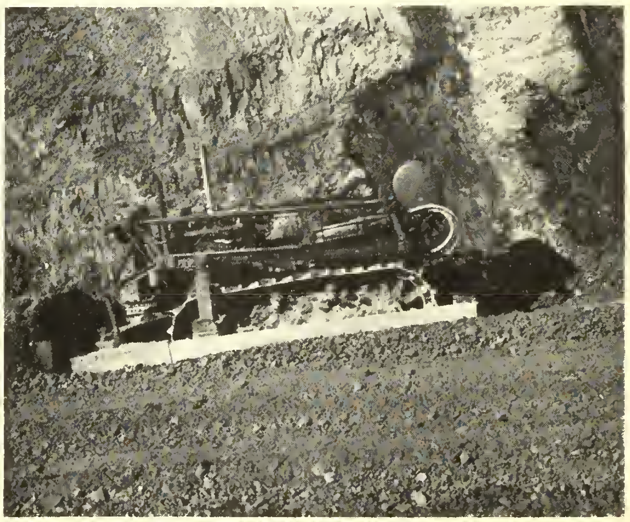
Recent improvements in control which permit independent vertical movement of either end of the bulldozer and also lateral movement have considerably improved the utility. It is easier to keep the entire cut in proper condition for easy operation, and to shape



A, Scraper Without Front Closure in Loading Position. Load is Dumped by use of Cable Which Pulls Back Plate Forward. B, Scraper with Full Load and Pushing Earth Before It. C, Scraper Arriving at Dump with a Full Load. D, A Type of Scraper which Dumps by Overturning on Front Shoes.

Table 1.—*Operation characteristics of tractor-powered bulldozers*

	Bulldozer no			
	1	2	3	4
Number of trips timed	3,731	511	800	560
Cubic yards placed in fill	11,741	1,655	1,822	1,352
Production rate......cubic yards per hour	68.4	57.0	35.2	44.1
Pay yardage per load......cubic yards	3.15	3.24	2.28	2.41
Loading distance......feet	30.0	40.0	28.0	39.0
Loading speed......feet per second	2.4	2.4	1.4	2.7
Haul distance......feet	168	216	309	232
Hauling speed......feet per second	3.7	3.2	3.2	3.1
Return distance......feet	200	260	340	275
Return speed......feet per second	2.3	2.5	4.7	2.5
Average grade......percent	−26	−17	−11	−20
Operating cycle:				
Load......seconds	12.6	16.6	20.6	14.3
Reverse or turn at dump......do	1.9	2.0	2.6	2.5
Turn or shift at cut......do	2.0	2.4	2.8	2.4
Minor time losses, percentage of working time	12.6	14.5	18.0	16.2
Size of blade......feet	4 by 10	3 by 11.5	4 by 10	4 by 10
Rated horsepower of tractor	65	65	60	60



Material Loosened by Scarifying and Moved with a Bulldozer.

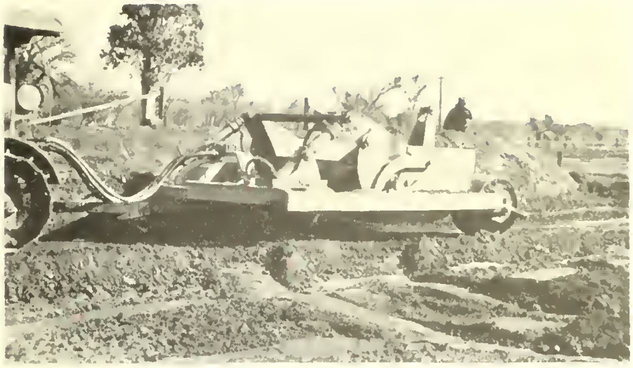
the slopes at the proper angle. These features are particularly valuable in sidehill work.

LARGE TRACTOR-DRAWN SCRAPERS STUDIED

Large tractor-drawn scrapers have been studied on a few grading jobs having large quantities of short-haul common excavation. These scrapers ranged in rated capacity from 3 to 8 cubic yards of loose material and were of six different makes. This number of different makes indicates that this type of equipment is far from standardized. However, those observed may be divided into two distinct classes: Those which carry the load pan or scoop clear of the road, and those which drag the load pan or cutting blade so as to transport a part or all of the load by pushing it ahead of the pan or cutting blade.

Some of those which lift the pan have definite provisions for preventing or reducing spillage while the load is being hauled to the dump. These provisions vary from substantial self-closing gates to simply tilting the load pan to such an angle that the tendency for the material to spill out is greatly reduced. In the other class, the pan is raised very little for the haul and spillage is prevented or at least neutralized by accumulating and dragging material in front of the pan.

Loading a Large Scraper.



End-Gate Type of Scraper in Hauling Position, Showing Gate Closed and Body Clear of Ground in Hauling Position.

Scarifying Material for Easy Loading by Scrapers or Bulldozers.

Table 2.—*Operating characteristics of large scrapers*

	Scraper no.							
	1	2	3	4	5	6	7	8
Rated capacity cubic yards	3	6	8	4	5	4	4	5
Condition of equipment	Good	Very good	Very good	Very good	Very good	Fair	Good	Fair
Number of round trips timed	212	269	132	145	54	56	3, 200	963
Loading distance feet	75	116	144	80	86	92	100	38
Loading speed feet per second	2. 3	1. 8	2. 0	2. 1	2. 0	1. 8	2. 0	2. 3
Hauling distance feet	180	327	290	210	372	1, 400	300	237
Hauling speed feet per second	2. 9	3. 5	2. 8	3. 0	3. 2	3. 0	2. 5	3. 3
Return distance feet	254	405	449	280	450	1, 450	400	275
Return speed feet per second	3. 2	3. 8	3. 8	3. 7	3. 8	4. 7	5. 5	2. 7
Dumping time seconds	10. 4				46. 0	34. 0	11. 0	10. 4
Turning time do	18. 0	22. 0	20. 0	24. 0	27. 0	22. 0	20. 0	
Size of load carried to dump, percentage of apparent full load	95. 0	75. 0	50. 0	90. 0	61. 0	75. 0	90. 0	
Average pay yardage in percentage of rated load capacity	57. 0	45. 0	35. 0	54. 0	37. 0	45. 0	53. 0	44. 0

Adjusting the pan so as to drag material produced a considerable effect on the hauling speed. When the scraper was hauled with the load pan clear of the ground the hauling speed was generally 30 to 50 percent higher than when the pan dragged sufficiently to retain a full load. The effect of reduced speed, however, seemed fully compensated by the increased load. With the pan hoisted entirely clear of the roadway, the loss from spillage on steep or rough down grades was as much as one half of the original load when the soil was dry and noncohesive. Considerable difficulty was sometimes experienced in dumping the gate type of scraper when working in sticky or plastic materials.

Results of observations on four jobs using six different types of scrapers are shown in table 2. Scrapers 1, 2, 3, 4, and 5 were all on one job and operated under fairly similar conditions. Job 7 was observed only in the winter when the materials were wet, sticky, and difficult to handle. Scrapers and 1 and 7 and 5 and 6 were of the same make and type but were observed on different jobs and under different conditions.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF APRIL 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$4.185.067.00	$133,076.15	$73.641.88	$59.434.27	5.0	$5,154,764.40	$2.850.690.43	$2.304,073.97	47.2	287.4	$366.087.29	25.6	$894.647.40
Arizona	3.804.731.00	1.178.418.45	1,178,418.45		79.5	2,763.906.32	2.204,970.38		32.5	191.5	191.326.54	5.8	230,015.63
Arkansas	3,374.167.00	118.950.68	84.285.68	34,665.00	6.0	2.401,810.33	1.959,044.89	442,765.44	41.1	111.8	547.468.32	50.0	783.368.11
California	7,803,677.00	1.603.685.04	1.363.993.73		60.1	7.711,638.66	5.755.125.65		36.3	212.9	642.341.58	29.1	42.216.04
Colorado	3,437.265.00	1,055.865.36	1,055,865.36		76.2	2.019.670.24	2,009.089.89		35.1	61.0	231.925.98	7.1	140.383.77
Connecticut	1.404.213.00					1,540,038.02	1,364,259.08	175.778.94	12.4	30.7	36,199.68	.1	3.754.24
Delaware	909.544.00	133.532.30	133.532.30			760,029.30	760.029.30		31.8	17.4			15.982.40
Florida	2.615.917.00	531,031.10	375,168.86	155.862.24	17.6	2,603.100.11	1.973,078.14	629.411.87	54.7	91.4	111.884.12	7.0	155.785.88
Georgia	5.045,592.00	467.980.22	467,980.22		24.5	2,460,868.26	2.460.868.26		49.9	161.0	879.827.92	56.3	1.236.915.60
Idaho	2,166,858.00	453.733.29	450,147.98		52.4	1,448.016.23	1.436.689.50		41.9	106.0	72.674.31	15.4	207,346.21
Illinois	4.431.348.00					1.590,705.85	1.590,705.85		24.5	37.0	1.722.506.15	19.4	1.118,136.00
Indiana	4,717,786.00					2.271,340.43	2,271,340.43		33.3	74.7	1.840.720.20	45.2	605,725.37
Iowa	5,027,830.00	723.735.69	721.500.00		31.6	4,335,833.29	4,086.830.00		39.9	228.0	194.125.50	9.5	25.374.50
Kansas	5,044,802.00	713,689.65	713.689.65		131.2	4,291.580.19	4,127.302.66		54.5	261.2	202,628.05	5.2	1,181.64
Kentucky	3.608.332.00	148,867.77	144.997.64		12.1	2.666.046.69	2.666.046.69		32.1	201.9	510.800.52	30.1	286,487.15
Louisiana	2.914,295.00	60,721.48	60.721.48		1.9	2.660.910.57	2,154.259.57		30.2	65.9	497.709.81	10.5	201.604.14
Maine	1,617,560.00					1,167,849.93	1.132,232.98		41.5	35.5	385,700.18	8.8	99.576.84
Maryland	1,782.263.00					801,143.78	791,495.03		15.5	14.8	316.871.75	6.4	673.896.22
Massachusetts	1,101.716,00	153.936.88	83,952.64	69.984.24	4.2	1.235.131.88	919,472.24	315.659.64	32.0	33.6	12,521.88		85,769.24
Michigan	5,094.491.00	63.000.00	63,000.00		1.7	3.491,050.00	3.491.050.00		28.1	177.3	1.540,441.00	61.9	
Minnesota	5,115,153.00	1.701.597.69	1.701.597.69		381.5	1.880.412.23	1.880,412.23		33.7	257.0	814,722.62	95.8	718.420.46
Mississippi	3.489.337.00	155.273.60	85.400.49	69.873.11	6.6	3,744,584.87	2,023.552.54	1,682,400.39	31.5	199.7	574.040.62	45.1	806,343.35
Missouri	5.237.532.00	522.010.24	397.362.24		28.7	4.306.843.30	3,940.425.23	50.048.60	43.9	148.1	344.047.92	11.8	555.696.61
Montana	4.463.849.00	784.377.15	784.377.15		77.9	3.772,325.19	3.359.523.76	332.801.43	34.2	257.1	278.767.99	23.7	41.180.10
Nebraska	3.914.481.00	377.339.04	255.419.54		144.8	4.378,870.30	3.280.762.23	108,538.00	49.2	203.0	378,298.23	14.0	1.00
Nevada	2,909.387.00	553.682.77	553.682.77		82.5	2,078,604.14	2,078,604.14		32.1	170.2	260,637.03	7.4	16.463.06
New Hampshire	725.739.00					584.339.36	577.831.95		46.0	9.8	68,469.25	1.0	79.437.80
New Jersey	3.099,370.48	12.742.75	12.742.75		.2	2,725,372.69	2.570.451.68	139.466.42	10.7	34.6	16.272.89		499.903.16
New Mexico	2,896,467.00	1.370.897.67	1,370.897.67		165.5	1.586,318.70	1.449.959.22	102.921.33	17.7	111.7	44.621.19	1.8	30.988.92
New York	10.271.846.00	315.707.14	215.707.14	43,000.00	7.4	10,717.688.68	9.552.963.68	315.000.00	24.3	221.5	445.487.15	10.8	57.688.03
North Carolina	4.761.147.00	667.973.20	410.195.45	257.777.75	53.5	2.620.617.03	2.303.365.92	316.790.92	45.0	367.7	1.143.228.39	160.5	904.357.24
North Dakota	2,902.224.00	510.757.38	510.753.87		265.8	1.332.394.06	1,280.222.21	52.171.85	18.9	368.3	882.547.23	284.6	228.700.69
Ohio	7.277.758.00	415.362.41	413,768.57		9.7	6,908.623.00	6,614.390.00	51.410.00	35.1	173.6	202.600.00	8.4	46,999.43
Oklahoma	4.608,399.00	305.249.23	305.140.15		21.9	3,708,272.93	3.708.272.93		45.2	246.2	233.819.14	29.6	361,166.78
Oregon	3,053.448.00	630.587.33	518.376.33		50.2	2.468,032.27	2.312.693.07	58.505.67	37.3	126.9	179.484.99	6.0	42.893.61
Pennsylvania	6.691,194.00	15,425.22	15.425.22		.2	5.468.094.10	5.424.889.93		17.6	115.2	915.209.55	14.9	335.669.30
Rhode Island	999.354.00	18.144.13	18.144.13		.5	979.621.58	979.621.58		32.6	20.0			1.588.29
South Carolina	2,729.583.00	51.527.78	51.527.78		.9	1.962,686.24	1.959.956.62	2.729.62	46.4	184.4	367.445.24	35.7	350,653.36
South Dakota	3.005,739.00	702,954.32	683,612.93	19.341.39	120.3	1.457.393.87	1.367.255.45	90.138.22	30.9	240.5	588.556.54	87.2	366.314.08
Tennessee	4.246.309.00	335,262.04	249.789.43	85,472.61	11.5	3.582,358.40	3.091.813.63	490.544.77	38.3	135.9	654.994.21	38.4	249.711.73
Texas	12.122,012.00	1.605.728.44	1,204.742.39		321.9	9.029.593.61	8,146.344.52		36.8	608.7	1.194.113.68	93.3	1,576.811.41
Utah	2.374,205.00	973.028.84	971.166.45		110.2	1.193,094.86	1,165,183.77		35.5	83.1	69.948.52	1.5	167.906.26
Vermont	928.184.00	47.983.81	47.983.81		6.2	735.351.85	707.198.60		38.8	34.7	158.637.24	4.0	14.364.35
Virginia	3.708.379.00	412.940.60	395.367.62	17.572.98	16.5	2.614.973.41	2.504.313.45	110,659.96	30.6	76.2	732.555.06	53.7	76,142.87
Washington	3.057.934.00	334.913.47	334.229.63		17.5	2.305.188.36	2.301.831.54	3.356.82	39.0	78.0	418,666.27	11.4	3.206.56
West Virginia	2.013,405.00	194.881.82	194.881.82		6.4	1,613.052.72	1,607,052.72		42.3	63.7	131,760.68	2.2	79.709.78
Wisconsin	4.862,441.00	307.513.14	297,210.31	1.190.00	15.7	2,770.852.54	2.702,036.77	21.500.00	37.2	109.0	1,463.244.04	97.7	399.949.88
Wyoming	2.250,663.00	912,725.90	797.131.00	78.000.00	163.8	1,432,898.15	1.313,540.00	58,200.00	18.9	280.0	107.708.02	14.7	32.283.98
District of Columbia													
Hawaii	1.683.956.00	85,729.28	72,722.15	12.994.32	4.2	1.379.099.46	1.143,819.31	185,280.15	22.7	25.3	218.720.78	3.3	248.693.76
TOTALS	185.486.949.48	21.862,540.45	19.840,252.35	905.167.91	2.596.0	142.712.992.38	127.352.919.65	8,040.154.01	34.9	7.351.1	23,192,365.25	1.551.9	15.101.412.23

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF APRIL 30,1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 2.092.533	$ 94,891.56	$ 94.891.56		1.5	$ 513,265.88	$ 513,265.88		18.3	16.1	$ 668.475.73	19.4	$ 815.899.83
Arizona	781,794	22,538.90	22,538.90		.8	218,896.37	217,455.49		52.9	6.3	386,886,59	4.3	154.913.02
Arkansas	1,687,084	17,506.70	15.826.70	$ 1,680.00	.3	815,777.57	737,822.36	$ 77,955.21	46.6	23.1	743,738.90	13.1	189.696.04
California	3.901.839	624,384.83	561,419.81		9.1	2,347.828.51	2.107,471.21		19.4	29.2	972.565.01	11.1	260.382.97
Colorado	1.718.633	267,964.98	222.157.33		5.6	909.226.59	909,226.59		29.3	17.2	452.837.21	10.6	134.411.87
Connecticut	802,407	48.325.68	48.325.68		.5	677,318.83	676.491.74		29.0	9.2	68.293.81	.5	9.295.77
Delaware	454.772	75.309.50	75.309.50		.8	196,685.90	196,685.90		11.7	1.9	81.105.00	1.0	101.671.60
Florida	1.307.959	120,149.54	66,194.72	53.954.82	2.0	1,407,312.64	1.223.502.25	183.810.39	28.8	15.2	18,262.03	.2	
Georgia	2.724.620	168,636.21	168.636.21		7.1	761.533.73	761.533.73		31.6	26.5	479,128.55	16.1	1.315.321.51
Idaho	1,197,829	35.981.47	35.773.52		1.8	417,310.23	411.366.65		37.9	10.6	424.722.40	3.0	325.966.43
Illinois	6,877.199	58.782.38	58,782.38		.8	5.812.406.26	5.812.406.26		16.0	60.5	1.006.010.36	9.7	
Indiana	4,818.165	42,730.27	42.730.27		.8	390.182.76	390.182.76		2.3	9.9	3.003.164.55	56.1	1.382,087.42
Iowa	2.815.585	243.532.64	242,350.00		8.6	1.180.110.31	1,107,595.00		27.1	23.5	524.474.50	14.4	941,165.50
Kansas	2,522,401	114.205.11	114,205.11		5.4	2.382,465.43	2,230.057.18		43.7	28.9	177.763.60	2.6	375.11
Kentucky	2,029,687	13,307.85	13.307.85		.2	562,107.36	562.107.36		14.4	11.7	410.045.28	11.7	1,044.226.51
Louisiana	1.457,148	159.911.74	159.911.74		2.5	294.238.30	294.238.30		54.4	9.5	1.002.997.96	15.1	
Maine	909.878	78,429.27	78.305.71		1.6	415.559.35	415.559.35		36.6	9.9	339.937.36	5.2	76.075.58
Maryland	891.132					16,788.76	12,638.76		99.0	.6			878.493.24
Massachusetts	5.007,199	53.896.49	30.896.49	23.000.00	1.5	3.946.565.68	3.932.465.68	14.100.00	19.7	12.7	250.293.28	1.0	793.543.55
Michigan	4.457,679	180.700.00	180,700.00		2,3	2,428,266.00	2,426.116.00		10.8	29.8	598.975.00	7.2	1,251.888.00
Minnesota	3.410.102	587.385.43	587,385.43		38.5	1,061.746.24	1,061,746.24		32.8	33.3	573,083.10	17.6	1,187,887.23
Mississippi	1,744,669	103,306.43	99.556.17	3.750.26	2.9	379.382,30	370.673.06	8,709.24	8.1	15.9	319.297.77	11.3	955,142.00
Missouri	4.019.501	79.441.39	77.155.86		2.2	1,722.682.85	1.584.251.58		53.7	30.9	689.512.52	12.8	1.668,581.04
Montana	1.115,962	8.857.31	8,857.31		1.0	560,206.07	560,206.07		26.4	14.7	379.417,34	12.3	167.481.28
Nebraska	1.957.240	28.782.40	28,093.11		3.6	1.452,124,90	1.452.124.90		24,0	21.7	476.567.75	8.0	454,24
Nevada	500.051	50,304.27	50.304.27		1.2	45.973.80	45.973.80			1.3	331.880.89	5.7	71,892.04
New Hampshire	706,640					592.825.47	592.825.47		15.7	14.4	113,814.53	2.1	
New Jersey	3.190.118	99.752.39	99,752.39		2,1	2.605.324,28	2,551.191.28	30,000.00	26,6	18.6	123.082.10	.5	416.092.23
New Mexico	1.448,234	132.598,88	132,598.88		5.3	1.087,965.44	1,087,965.44		21.9	20,3	81,974.48	4.1	145.695.20
New York	8.449.487	123.574.54	123,193.24		2.1	7.356.177.60	6,907.745.00	39,000.00	21.1	56,9	725.252.70	3.0	693,296.06
North Carolina	2.380.573	136,289.35	136.289.35		7.3	708.428.99	706,793.70		25.6	29.6	474.703.51	20.0	1,062.786.44
North Dakota	1,451,112	2,153.29	2,153.29		1.0	231.430.79	204,421.06	27.009.73	18.6	11.7	522.161.67	18.9	722.375.98
Ohio	4.335.686	73,956.80	62,264.08		2.0	3,590.564.43	3.215.249.43		18.3	41.9	964,984.00	14.0	93.188.49
Oklahoma	2,304.200	36,756.66	36.740.13		2.5	1.506.053.88	1.506.053.88		24.0	28.6	514,514.25	12.6	246,891.74
Oregon	1.526,724	99.566,50	99.566,50		2.0	1,080,582.35	1,059.218.76	14.315.73	21.2	19.6	87.027.53	3.7	280.911.21
Pennsylvania	4.854.988	178.972.50	178.140.66		5,1	2,050,367.30	2,006.816.04		26.7	33.1	1.516.324.34	17.5	1.153.706.96
Rhode Island	499.677					351.090.02	351.090.02		12.0	5.3	66.224.98	1.1	82.362,00
South Carolina	1,364.791	37.322.12	37.322.12		2.0	427,299.38	426,894.37	405.01	31.6	20.9	302.359.13	10.8	598.215.38
South Dakota	1,502.870	148.279.48	148.279.48		7.0	286,290.13	286.290.13			9.3	670.760.85	21.0	397.539.54
Tennessee	2,123.155	89.510.69	89.510.69		2.5	949,476.28	949,476.28		30.8	12.7	320,432.68	5.8	763.735.35
Texas	6,061.006	422.531.62	383.362.80		22.1	2,963.557.58	2.809.482.00		30.9	62.0	1.328,910.87	24.6	1.539.250.33
Utah	771,826	402.641.81	391.682.07		9.0	194.944.70	193.186.32		68.3	5.9	60.000.00	1.8	126.957.61
Vermont	500.509	3.854.07	3.854.07		.7	385,151.18	375,663,48		18.1	10.2	120.991.45	3.7	
Virginia	1.854,189	184.013.92	174.362.04	9,651.88	6.5	1,302.512.21	1.105.439.73		16.3	13.1	557,167.32	7.8	17.219.91
Washington	1.877.571	286.522.39	275.125.01		6.1	1.597.697.40	1.594.992.67		27.7	25.7	7,453.32	.4	
West Virginia	1,342,270	15.323.43	15.323,43		.4	787,263.82	762.918.08		19.0	13.5	280.083.23	5.8	283,945.26
Wisconsin	2,431,220	151.529.60	151.529.60		4.7	831,311.48	825.004.65		35.3	18.7	1.184.326,08	24.5	270.359.67
Wyoming	1.125,332	53.504.69	53,004.69		1.0	728.480.25	728.477.07		18,3	15.1	181.882.46	3.2	161,967.78
District of Columbia	959.235	295.510.62	295,510.62		2.4	680,633.97	663.650.15		31.0	2.3			74.23
Hawaii													
TOTALS	114.264,481	6,253.427.70	5.973.180.77	92.036.96	196.4	63.211.391.55	60.924.009.11	395,305.31	24.5	959.5	24.583.867.97	476.9	22,783.423.15

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF APRIL 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2.092.533.00				$ 135.095.17	$ 135.095.17	40.7	5.1	$ 888.321.80	64.5	$ 1.069.116.03	Alabama
Arizona	625.435.00				412.835.88	400.873.89	43.4	32.2	125.602.58	10.1	98.958.53	Arizona
Arkansas	1.687.084.00	$ 11.141.83	$ 11.141.83	0.2	677.384.93	677.384.93	16.5	79.1	355.548.25	57.3	643.008.99	Arkansas
California	3.901.838.00	226.532.81	161.925.10	2.5	2.723.965.67	2.259.569.95	32.0	141.9	641.304.79	23.2	839.038.16	California
Colorado	1.718 632.00	269.262.42	269.262.42	41.7	1.211.910.29	1.176.489.22	50.5	131.2	160.097.64	9.7	112.782.72	Colorado
Connecticut	659.120.00				664.915.58	659.120.00	10.8	14.5				Connecticut
Delaware	454.772.00				161.554.00	161.554.00	15.5	1.8	72.547.50	12.2	220.670.50	Delaware
Florida	1.307.958.00	166.491.36	166.491.36	19.0	1.049.502.53	1.049.802.53	50.6	49.4	38.729.77	.5	52.934.34	Florida
Georgia	2.320.973.00				650.256.71	650.256.71	40.9	42.3	510.335.81	51.1	1.160.380.48	Georgia
Idaho	1.121.562.00	240.026.23	230.797.07	34.3	948.331.25	890.764.93	41.2	111.4				Idaho
Illinois	6.262.223.00	90.725.91	90.725.91	23.1	4.016.285.04	4.016.285.04	17.5	239.3	1.128.576.05	55.4	1.026.636.00	Illinois
Indiana	501.592.00				380.774.32	380.774.32	13.9	52.9	121.117.68	16.2		Indiana
Iowa	2.212.245.00	85.658.05	83.000.00	27.3	1.049.582.42	998.950.00	34.7	127.7	844.700.00	86.2	285.595.00	Iowa
Kansas	2.522.401.00	11.865.47	11.865.47	3.8	2.038.501.25	2.027.934.29	35.2	151.0	467.585.91	9.5	15.015.33	Kansas
Kentucky	1.879.340.00	181.969.52	181.969.52	22.4	1.453.742.94	1.453.742.94	29.6	172.0	202.881.88	21.1	40.745.66	Kentucky
Louisiana	1.457.148.00	61.627.65	61.627.65	2.3	540.534.03	540.534.03	12.0	27.9	593.981.05	16.0	260.705.27	Louisiana
Maine	842.479.00	486.989.39	486.986.99	49.7	420.558.60	340.074.53	91.7	36.5	8.989.70	.2	6.427.78	Maine
Maryland	891.132.00				448.056.92	448.056.92	30.1	34.9	280.626.45	18.3	162.448.63	Maryland
Massachusetts	488.185.00				469.741.41	469.741.41	42.2	15.2			18.443.59	Massachusetts
Michigan	3.184.057.00	88.500.00	88.500.00	7.4	2.387.000.00	2.387.000.00	9.6	185.4	421.950.00	31.8	286.607.00	Michigan
Minnesota	2.131.314.00	45.666.23	45.666.23	34.6	1.557.346.39	1.476.915.39	39.8	223.5	194.428.52	9.2	414.303.86	Minnesota
Mississippi	1.744.669.00				459.999.99	459.999.99	52.8	54.6	337.534.77	37.1	947.134.24	Mississippi
Missouri	2.923.273.00	30.275.23	30.275.23	7.7	2.623.965.44	2.623.965.44	56.6	467.7	250.117.33	20.1	18.915.00	Missouri
Montana	1.859.937.00	250.772.55	250.772.55	33.6	1.295.827.72	1.295.827.72	3.5	160.5	281.627.19	28.7	31.709.54	Montana
Nebraska	1.957.240.00	16.621.93	16.621.93	15.2	1.849.229.15	1.829.980.23	39.5	241.6	110.637.84	27.1		Nebraska
Nevada	1.136.479.00	187.125.76	187.125.76	14.5	792.873.50	792.873.80	49.5	86.2	36.585.76	2.7	119.593.68	Nevada
New Hampshire	477.460.00				518.207.67	477.383.82	47.3	25.6			76.18	New Hampshire
New Jersey	56.550.52				56.550.52	56.550.52	30.1	.5				New Jersey
New Mexico	1.448.234.00	291.500.00	291.500.00	64.7	652.000.00	652.000.00	57.4	247.8	95.499.53	10.9	409.234.47	New Mexico
New York	3.608.768.00	233.621.33	233.621.33	10.8	3.786.800.00	3.355.375.00	19.4	88.7	9.275.00	.1	10.496.67	New York
North Carolina	2.380.573.00	158.831.55	158.631.48	18.4	1.087.336.67	1.087.336.67	54.2	98.9	211.203.47	26.7	923.401.38	North Carolina
North Dakota	1.451.112.00				46.035.01	46.035.01	10.9	10.3	230.270.50	32.5	1.174.506.49	North Dakota
Ohio	3.871.148.00	225.440.00	225.440.00	78.3	3.261.880.00	3.024.904.90	27.6	215.8	416.200.00	7.8	204.603.10	Ohio
Oklahoma	2.304.199.00				590.374.75	590.374.75	16.6	55.0	1.635.542.71	210.4	78.281.54	Oklahoma
Oregon	1.526.724.00				1.129.874.44	1.019.991.42	36.9	60.5	486.658.00	48.0	20.074.58	Oregon
Pennsylvania	7.344.822.00	40.096.00	40.096.00	4.9	6.424.728.04	6.350.125.84	28.5	588.5	734.160.25	63.3	220.439.91	Pennsylvania
Rhode Island	499.677.00				412.010.22	412.010.22	11.4	33.2			87.666.78	Rhode Island
South Carolina	1.364.791.00				1.174.986.08	1.174.986.08	44.0	133.8	110.233.65	12.7	79.571.27	South Carolina
South Dakota	1.502.870.00	66.805.85	66.805.85	32.8	247.149.43	247.149.43	22.2	75.6	140.607.64	54.9	1.048.307.08	South Dakota
Tennessee	2.123.155.00				1.082.015.78	1.082.018.78	34.9	89.1	465.207.98	40.3	575.928.24	Tennessee
Texas	6.061.006.00	752.743.58	565.520.59	134.5	5.142.149.72	4.422.255.78	46.0	601.7	398.089.67	27.6	675.139.96	Texas
Utah	1.048.677.00	382.032.68	365.511.34	69.5	560.641.16	544.391.65	35.6	86.7	93.967.69	8.0	44.806.32	Utah
Vermont	438.880.00				336.541.00	318.237.70	24.2	29.2	120.163.79	7.2	478.51	Vermont
Virginia	1.854.189.00	82.084.91	65.000.72	31.0	1.390.470.60	1.307.685.69	50.3	173.0	369.036.69	4.4	112.465.90	Virginia
Washington	1.180.362.00	131.043.12	131.043.12	16.2	925.200.89	915.200.89	28.2	47.2	27.739.30	5.9	106.378.69	Washington
West Virginia	1.118.559.00	5.979.96	5.979.96		896.461.92	896.461.92	16.1	50.7	141.115.69	9.1	75.001.43	West Virginia
Wisconsin	2.431.220.00	223.248.44	223.248.44	7.8	1.540.061.70	1.465.214.29	12.6	98.2	578.231.84	63.1	164.525.43	Wisconsin
Wyoming	1.125.332.00	388.313.29	377.284.00	48.4	596.172.42	588.978.00	17.3	91.4	102.371.05	10.9	56.698.95	Wyoming
District of Columbia	959.234.00	110.674.64	110.674.64	2.0	848.409.36	848.409.36	26.8	5.7			150.00	District of Columbia
Hawaii	187.106.00				177.717.69	177.717.69	23.1	4.9			9.388.31	Hawaii
TOTALS	94.248.569.52	5.543.667.69	5.235.112.49	859.2	63.304.749.50	60.664.662.79	32.1	5.800.8	14.439.402.72	1.250.3	13.909.391.52	TOTALS

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AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF APRIL 30, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8.370.133	$ 227.967.71	$ 168,533.44	$ 59.434.27	6.5	$ 5.803.125.45	$ 3,499.051.48	$ 2.304.073.97	42.7	308.6	$ 1.922.884.82	109.5	$ 2.779.663.26
Arizona	5.211.960	1.200.957.35	1.200.957.35		80.3	3.395,638.57	2.823,299.76		35.6	230.0	703.815.71	20.2	483,887.18
Arkansas	6.748.335	147.599.21	111.254.21	36.345.00	6.5	3.894.972.83	3.374.252.18	520.720.65	37.5	214.0	1.646,755.47	120.4	1.616,073.14
California	15.607.354	2.454,602.68	2,087.338.64		72.0	12.783.432.84	10.122.166.81		31.8	384.0	2.256,211.38	63.4	1.141.637.17
Colorado	6.874.530	1.593,092.76	1.547.285.11		123.5	4.140,807.12	4.094,805.70		38.2	209.4	844,860.83	27.4	387.578.36
Connecticut	2.865.740	48,325.68	48,325.68		.5	2,882.272.43	2.699,870.82	175.778.94	16.1	54.4	104,493.49	.6	13,050.01
Delaware	1.819.088	208,841.80	208.841.80		.8	1.118.269.20	1.118,269.20		25.9	21.1	153.652.50	13.2	338.324.50
Florida	5.231.834	817,672.00	607,854.94	209.817.06	38.6	5,060,215.28	4.246,382.92	813.222.26	46.2	156.0	168.875.92	8.0	208.720.22
Georgia	10.091.185	636.616.43	636.616.43		31.6	3,872,658.70	3.872,658.70		44.8	229.8	1,869,292.28	123.5	3,712.617.59
Idaho	4.486.249	729.740.99	716,718.57		88.5	2.813.657.71	2.738.821.08		41.1	228.0	497.396.71	18.4	533.312.64
Illinois	17.570.770	149.508.29	149.508.29		23.9	11,419,397.15	11.419,397.15		17.7	336.8	3.857,092.56	84.5	2,144,772,00
Indiana	10.037.843	42,730.27	42.730.27		.8	3.042.297.51	3,042,297.51		26.9	137.5	4,965,002.43	117.5	1,987.812.79
Iowa	10,055.660	1.052.926.38	1.046.850.00		67.5	6.565,826.02	6.193.375.00		36.8	379.2	1.563,300.00	110.1	1.252.135.00
Kansas	10,089,604	839,760.23	839,760.23		140.4	8,712.846.87	8.385,294.13		47.0	441.1	847.977.56	17.3	16.572.08
Kentucky	7.517,359	344.145.14	340,275.01		34.7	4,681,896.99	4,681,896.99		29.2	385.6	1.123,727.68	62.9	1.371.459.32
Louisiana	5.828,591	282,260.87	282,260.87		6.7	3.495,982.90	2,989.331.90		29.3	103.3	2.094,688.82	41.6	462.309.41
Maine	3,369.917	565.418.66	565.292.70		51.3	2.003,967.88	1,887.916.86		49.5	81.9	734,627.24	14.2	182.080.20
Maryland	3.564,527					1.265,989.46	1.252,190.71		21.6	50.3	597,498.20	24.7	1,714.838.09
Massachusetts	6.597.100	207.833.37	114.849.13	92.984.24	5.7	5.651,438.97	5.321,679.33	329.759.64	83.8	61.5	262.815.16	1.0	897,756.38
Michigan	12.736.227	332,200.00	332.200.00		11.4	8,306,316,00	8,304,166.00		17.7	392.5	2.561,366.00	100.9	1,538,495.00
Minnesota	10.656.569	2,334,649.35	2.334.649.35		454.6	4.499.504.86	4.419,073.86		35.5	513.8	1.582.234.24	122.6	2,320,611.55
Mississippi	6.978.675	258.580.03	184.956.66	73.623.37	9.5	4,583.967.16	2.854.225.59	1.691,109.63	31.9	270.2	1.230,873.16	93.5	2,708.619.59
Missouri	12,180.306	631,726.86	504.793.33		38.6	8,653,491.59	8,148,642.25	50,048.60	49.9	646.7	1.283.677.77	44.7	2.243,192.65
Montana	7.439.748	1.044.007.01	1.044.007.01		112.5	5.628.358.98	5.215.557.55	332,801.43	25.7	432.3	939.812.52	64.7	240.370.92
Nebraska	7.828.961	422.743.37	300,134.58		163.6	7,680,224.35	6,562.867.36	108,538.00	40,9	466.3	965.503.82	49.1	455.24
Nevada	4.545.917	791,112.80	791,112.80		98.5	2,917.451.74	2,917.451.74		36.4	257.7	629.103.68	15.8	208.248.78
New Hampshire	1.909.839					1.695.372.50	1.648,041.24		35.5	49.8	182.283.78	3.1	79.513.98
New Jersey	6.346,039	112.495.14	112.495.14		2.3	5.387.247.49	5,178.193.48	169.466.42	18.7	53.7	139.354.99	.5	915.995.39
New Mexico	5.792.935	1.794.996.55	1.794.996.55		235.5	3.326,284.14	3.189.924.66	102.921.33	27.2	379.8	222.095.20	16.8	585.918.59
New York	22.330.101	672.903.01	572.521.71	43.000.00	20.3	21.860.666.28	19,816.083.68	354.000.00	22.4	367.1	1.180.014.85	13.9	761.480.76
North Carolina	9.522.293	963,094.10	705.116.28	257.777.75	79.2	4.416.382.69	4.097.496.29	316.790.92	44.1	496.2	1.829,135.37	207.2	2.890,545.06
North Dakota	5.804.448	512.910.67	512.907.16		266.8	1,609,859.86	1.530,678.28	79,181.58	18.6	390.3	1.634,979.40	336.0	2.125,883.16
Ohio	15.484.592	714.759.21	701.472.65		90.0	13,761.067.43	12.854,544.33	51.410.00	29.1	434.3	1.583.784.00	30.2	344.791.02
Oklahoma	9.216,798	342.005.89	341,880.28		24.4	5.804,701.56	5,804.701.56		36.8	329.8	2.383.876.10	252.6	686,340.06
Oregon	6.106.896	730.153.83	617.942.83		52.2	4.678,489.06	4,391.903.25	72.821.40	33.3	207.0	753,170.52	57.7	343,879.40
Pennsylvania	18.891,004	234,493.72	233.661.88		10.2	13.943,189.44	13.781.831.81		23.9	736.8	3,165,694.14	95.7	1.709,816.17
Rhode Island	1,998.708	18.144.13	18.144.13		.5	1.742.721.82	1.742,721.82		23.4	58.5	66.224.98	1.1	171.617.07
South Carolina	5.459.165	88.849.90	88.849.90		2.9	3.564.971.70	3.561.837.07	3.134.63	43.8	339.1	780.038,02	59.2	1,028,440.01
South Dakota	6.011.479	918,039.65	898.698.26	19.341.39	160.1	1.990,833.43	1,900,695.01	90.138.22	25.1	325.4	1.399.925.03	163.1	1,812.160.70
Tennessee	8.492.619	424.772.73	339.300.12	85.472.61	14.0	5.613.853.46	5.123.308.69	490,544.77	36.2	237.7	1,440.634.87	84.5	1,589.375.32
Texas	24.244,024	2.781.003.64	2,153.625.78		478.5	17.135.300.91	15,378.082.30		38.3	1.272.4	2.921.114.22	145.5	3.791.201.70
Utah	4.194.708	1.757,703.33	1,728.359.86		188.7	1.948.680.72	1,902,761.74		38.8	175.7	223 916.21	11.3	339.670.19
Vermont	1.867.573	51.837.88	51.837.88		6.9	1.457.044.03	1,401.099.78		29.9	74,1	399,792.48	14.9	14.842.86
Virginia	7.416.757	679.039.43	634.730.38	27,224.86	54.0	5.307.956.22	4.917.438.87	110,659.96	32.6	262.3	1.658,759.07	65.9	205,828.68
Washington	6,115.867	752.478.98	740.397.76		39.8	4,828.086.65	4.812.025.10	3.356.82	33.2	150.9	453,858.89	15.7	109,585.25
West Virginia	4.474,234	216,185.21	216.185.21		6.8	3.296.778.46	3.266.432.72		29.6	127.9	552.959.60	17.1	438.656.47
Wisconsin	9.724.881	682.291.18	671.988.35	1,190.00	28.2	5.142,225.72	4.992.255.71	21.500.00	29.7	225.9	3.225,801,96	185.3	834.834.98
Wyoming	4.501.327	1.354.543.88	1.227,419.69	78.000.00	213,2	2,757.550.82	2,630,995.07	58.200,00	18.4	386.5	391,961.53	28.8	250,950.71
District of Columbia	1.918.469	406,185.26	406,185.26		4.4	1.529.043.33	1.512.059.51		28.6	8.0			224.23
Hawaii	1.871.062	85.729.28	72.722.15	12.994.32	4.2	1.556.817.15	1.321,537.00	185,280.15	22.8	30.2	218.720.78	3.3	258,082.07
TOTALS	394.000.000	33.659.635.84	31.048.545.61	997,204.87	3.651.6	269.229.133.43	248.941.591.55	8,435.459.32	31.6	14.111.4	62,215,635.94	3,279.1	51.794,226.90

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 4 ▽ JUNE 1934

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 4 June 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

A STUDY OF SOME LIQUID ASPHALTIC MATERIALS OF THE SLOW-CURING TYPE

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **R. H. LEWIS**, Associate Chemist, and **W. O'B. HILLMAN**, Junior Highway Engineer

THERE has been considerable progress in the simplification of tests and specifications for liquid asphaltic road materials, but there is still considerable difference of opinion as to the laboratory tests most highly indicative of the probable road or service behavior of liquid materials of the so-called slow-curing type.

PRESENT TESTS UNSATISFACTORY AS A BASIS FOR PREDICTING SERVICE BEHAVIOR OF SLOW-CURING MATERIALS

Unlike materials of the medium-curing and rapid-curing types, which are generally combinations of refined asphalts and more or less volatile solvents, and which in the laboratory tests readily lose these solvents, leaving residues possessing essentially the characteristics of the base asphalts, materials of the slow-curing type are of variable composition. They may be crude or reduced petroleums from various fields, blends of topped and residual petroleums with cracking coil residues, cracking coil residues of satisfactory fluidity, and blends of various residuals of widely different consistencies with more or less nonvolatile distillates.

It is still an open question as to what tests and specifications will adequately control and describe the most essential qualities of this type of liquid asphaltic road material. Many of those engaged in the testing and use of these products favor such tests as those for specific gravity, solubility in naphtha, fixed carbon, asphaltic residue and other tests less generally known. Others consider that only the original consistency and an accelerated evaporation test, with a purity and consistency test on the residue, are essentially important in judging or anticipating the road making qualities of a particular fluid product. An accelerated evaporation test is assumed to indicate in a relatively short time the amount of volatile matter lost in a long period of service and the probable consistency of the resulting residue. The accelerated evaporation tests most commonly used are the distillation tests, and the volatilization test or loss on heating at 325° F. for 5 hours.

Slow-curing materials, when subjected to either of these accelerated evaporation tests, yield residues which are fluid and not adapted to the usual tests for semisolid asphalts as are the residues from rapid-curing and medium-curing products. In order to determine the amount of semisolid asphalt which a given liquid asphaltic material may ultimately produce, and in many cases to ascertain the physical and chemical characteristics of this residue by tests usually made on semisolid asphalts, the test for residue of 100 penetration has been used by some testing engineers.

Slow-curing materials are used extensively as dust palliatives, in penetrative treatments such as oiling earth roads, in the so-called blotter treatments and in the oil-processed roads of the West. In these types of surface, the bituminous material is not directly exposed to the action of sun and air in any appreciable thickness, and for this reason it is held by some that if the liquid asphaltic material, when subjected to either the volatilization test or the distillation test, yields a fluid residue, then the material in the road will probably remain fluid. Others believe that the bituminous material does eventually become semisolid and that the characteristics of the residue of 100 penetration are not only typical of the asphaltic residue which ultimately forms the bituminous binder in the road surface but are also indicative of the serviceability of the original material as a road binder.

Slow-curing materials are altered in service by the loss of volatile matter and also by other factors. The residues obtained in the various laboratory evaporation tests may or may not be typical of service residues. Two slow-curing materials having identical test values, which initially function satisfactorily as dust palliatives, may show great differences in length of efficient service. Two products used in oil processed construction may develop smooth well bonded surfaces when first compacted, yet one may produce a road which can be successfully reprocessed after a long period and the other may produce a surface which rapidly hardens and ravels, requiring the use of additional oil during reprocessing. Many engineers, therefore, have developed tests and specifications which they hope will insure the purchase of liquid asphaltic materials from a particular field or process of manufacture which rendered adequate and economical service. These same tests and specifications may not guard against improper materials when the purchaser is dependent on products from another field or different process of manufacture.

Practically all specifications for slow-curing liquid asphaltic materials require some sort of accelerated evaporation test. The question therefore arises as to whether the accelerated laboratory evaporation tests do indicate the probable road behavior. Like most materials, whether organic or inorganic, bituminous materials suffer change and in many cases complete disintegration on exposure to the elements. Liquid asphalts of the kind considered, used to form a thin coat on mineral aggregate in the exposed surface of the road, no doubt undergo more severe changes on exposure than do the more carefully refined and more viscous asphaltic materials. It seems desirable that changes in physical and chemical characteristics which occur when slow-curing products are exposed to sunlight, heat, and air be studied and compared with the changes produced in the various laboratory tests.

SLOW-CURING MATERIALS SUBJECTED TO LABORATORY TESTS AND EXPOSURE TO SUN

With this end in view, 22 samples of liquid asphaltic products of the slow-curing type were selected and given a complete laboratory examination, consisting of all tests generally used in the control of materials of this kind. Samples were then exposed in films one-eighth inch thick to the action of air, light, and solar heat during the summer months of 1932. The loss of volatile matter was determined and the residues, together with the residues from the laboratory evaporation tests, were subjected to determinations which would indicate the extent of the physical and chemical changes occurring under both conditions.

In order to determine the binding value of the original materials and the residues obtained from various laboratory tests Hubbard-Field stability cylinders were prepared with a standard sand and the resulting cylinders tested for stability. Cylinders prepared with the original materials were also exposed to oven heat at 140° F. and to the same exposure conditions as the thin films. At stated intervals the loss of volatile matter and the stability were determined.

The samples selected for this study, with few exceptions, represent materials which will meet one of the provisional specifications for slow-curing liquid products recently developed cooperatively by the Bureau of Public Roads and the Asphalt Institute. They are the products of 10 refineries in the Far West and Middle West and, in most cases, will meet some of the specifications of the States dependent on these refineries for asphaltic materials for low-cost road construction. The samples are identified in table 1, which shows the State specifications which these materials were designed to meet and the cooperative specifications which they will meet.

The laboratory tests on the original materials were as follows:

Specific gravity at 77° F./77° F.
Flash point, ° F.
Saybolt-Furol viscosity at 122° F. and 140° F.
Float test at 77° F.
Volatilization at 325° F., 20 and 50 grams.
Residue, float at 122° F.
Distillation:
Residue:
Float at 122° F.
Solubility in carbon tetrachloride.
Distillate:
Specific gravity at 77° F./77° F.
Index of refraction at 77° F.
Residue of 100 penetration:
Penetration at 77° F. and 32° F.
Ductility at 77° F. and 34°–35° F.
Softening point, ° F.
Fixed carbon.
Solubility in 86° B. naphtha.
Solubility in carbon tetrachloride.
Solubility in carbon disulphide (in some instances).

The test for residue of 100 penetration or asphalt-content test will hereafter be called, as a matter of convenience, the asphaltic residue test, and the residue therefrom the asphaltic residue.

Tests were made, unless otherwise stated, in accordance with the standard or tentative standard methods of the American Society for Testing Materials or the American Association of State Highway Officials and the serial designations of these methods are given in table 2.

TABLE 1.—*Designation of samples and specification intended to be met*

Bureau of Public Roads laboratory no.—	Identification	Producer	Refinery	Specification intended to be met	Meets Bureau of Public Roads and Asphalt Institute provisiona specifications
35100	A	1	1	Illinois E-3	
35103	B	1	1	Illinois E-4	S.C.-2
35364	C	1	2	Illinois E-3	
35367	D	1	2	Illinois E-4	S.C.-2
35157	E	2	3	Northwestern Conference No. 2	S.C.-2
34263	F	2	4	Middle Western States 60–70	
34453	G	3	5		
34454	H	3	5	Northwestern Conference No. 2	S.C.-2
34322	I	4	6	Middle Western States 70–80	S.C.-2
34323	K	4	6	Middle Western States 70–80	S.C.-3
36310	L	5	7	Northwestern Conference No. 2	S.C.-2
36303	M	5	7	Colorado 60–70	
36300	N	5	7	California and New Mexico 70–80	S.C.-3
35225	O	6	8	Northwestern Conference No. 2	S.C.-2, 3
35226	P	6	8	Arizona	S.C.-2
35228	R	6	8	California and New Mexico 70–80	S.C.-3, 4
36106	S	5	9	Colorado 60–70	
36089	T	5	9	Northwestern Conference No. 2	S.C.-2, 3
36091	V	5	9	California and New Mexico 70–80	S.C.-3
35077	X	7	10	Arizona	
35080	Y	7	10	Northwestern Conference No. 2	S.C.-2
35081	Z	7	10	California and New Mexico 70–80	S.C.-3

TABLE 2.—*Designations of test methods used for various tests*

Test	A.S.T.M. serial no.	A.A.S.H.O. serial no.
Flash point, Cleveland open cup	D 92–24	T-48
Specific gravity	D 70–27	T-43
Furol viscosity	D 88–30	T-72
Float test	D 139–27	T-50
Penetration	D 5–25	T-49
Softening point, ring and ball	D 36–26	T-53
Ductility	D 113–26T	T-51
Loss at 325° F	[1] D 6–30	T-47
Residue of 100 penetration	D 243–28T	
Soluble in CS_2	D 4–27	T-44
Soluble in CCl_4		T-45
Insoluble in 86° B. naphtha		T-46
Fixed carbon	D 168–30	

[1] In A.S.T.M. standard method of test D 6–30 there is no provision for making the test with a 20 gram sample.

The distillation test was made in accordance with the A.S.T.M. Standard Method D 20–30, with the following exceptions:[1]

1. The sample distilled was 200 cubic centimeters at 77° F.
2. The bulb of the thermometer was immersed to a point one-quarter inch above the bottom of the flask.
3. The condenser was water cooled.
4. The distillate was collected in 100 cubic centimeter glass cylinders and the initial boiling point and the percentage of distillate by volume at 680° F. and every 18° F. below 680° F., was recorded. The weight of the total volume of distillate to 680° F. was also recorded.
5. The distillation was stopped at 680° F. and the entire residue poured immediately into 400 cubic centimeter pyrex beakers and cooled to room temperature. After weighing it was then warmed, thoroughly stirred and poured into covered containers for further tests.

The weight of the residue from distillation remaining in the flask after pouring was also determined. The weight of the sample minus the weight of the distillate and residue is the distillation loss. The distillation loss is relatively high because, when the residue is poured at the high temperature of 680° F. considerable volatile matter escapes during the pouring and cooling to room temperature. This loss is reported as loss on cooling. The percentage of distillate collected plus the percentage of loss on cooling is the total percentage

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[1] This is substantially the method recommended by the Bureau of Public Roads and the Asphalt Institute in the proposed simplified scheme of analysis, differing only in the amount of sample distilled, 200 cubic centimeters at 77° F. instead of 60° F., and in the receptacle for the residue. The 400 cubic centimeter beaker was used instead of the 8-ounce tin because the entire contents of the distillation flask could not be poured into the 8-ounce tin.

TABLE 3. *Tests on the original materials*

Identification	Specific gravity, 77° F./77° F.	Flash point, ° F.	Float at 77° F. second	Viscosity: Furol viscosity at 122° F. seconds	Viscosity: Furol viscosity at 140° F. seconds	Volatilization, 5 hours at 325° F.: 50 grams: Loss, percent by weight	50 grams: Float of residue at 122° F. seconds	20 grams: Loss, percent by weight	20 grams: Float of residue at 122° F. seconds	Organic matter insoluble in CS_2 percent	Organic matter insoluble in CCl_4 percent	Organic matter insoluble in 86 °B. naphtha, percent	Fixed carbon, percent	Asphaltic residue: Percent	Asphaltic residue: Time of reduction, minutes	Penetration: 77° F., 5 seconds, 100 grams	Penetration: 32° F., 60 seconds, 200 grams	Softening point, ° F.	Ductility, cm: 77° F., 5 centimeters per minute	Ductility, cm: 31-35 ° F., 5 centimeters per minute
A	1.001	250	9	94	53	8.1	20	12.5	35	0.19	0.83	11.0	8.6	65.0	55	87	19	113	110+	0
B	1.013	255	20	205	110	8.8	42	14.1	112	0.17	2.17	16.1	11.3	71.9	34	81	15	114	110+	0
C	0.942	195	2	68	47	15.7	17	22.1	12	--	0.08	6.8	6.1	66.5	330	95	25	118	110+	4.8
D	0.955	200	9	199	106	10.7	26	15.6	55	---	0.11	4.6	6.0	75.1	420	88	27	120	110+	4.8
E	0.976	295	36	294	152	5.0	29	6.0	30	-----	0.07	10.2	7.7	66.5	220	104	30	114	110+	6.0
F	1.066	280	20	94	48	5.5	23	7.8	27	0.07	0.50	16.0	8.1	64.0	65	101	9	108	110+	0
G	1.079	300	8	68	36	7.4	20	11.6	28	0.19	1.58	19.6	10.3	63.9	30	82	8	109	110+	0
H	1.101	305	65	297	123	4.6	43	6.8	60	0.58	2.03	22.7	12.5	75.1	30	92	8	109	110+	0
I	1.082	300	75	320	137	4.9	48	7.9	79	0.08	2.88	25.8	14.0	75.9	30	92	11	109	110+	0
K	1.088	315	100	478	188	4.0	52	6.2	82	0.09	2.83	25.1	14.6	78.1	25	100	14	108	110+	0
L	0.972	255	24	274	134	8.0	32	11.5	43	------	0.04	5.7	4.4	65.1	68	93	20	111	110+	0
M	0.967	215	7	151	80	11.4	30	16.1	54	--------	0.07	6.0	5.4	65.3	79	112	19	110	110+	0
N	0.981	270	48	677	295	5.8	48	8.3	63	-----	0.07	5.6	5.0	70.2	78	105	19	109	110+	0
O	0.972	320	25	300	148	4.7	24	6.9	28	------	0.13	7.6	4.9	65.2	107	101	26	113	110+	5.8
P	0.967	260	12	201	104	10.2	32	14.6	51	------	0.09	5.7	5.6	67.9	71	107	18	110	110+	1.0
R	0.979	330	71	735	333	3.8	44	5.7	50	-----	0.06	9.2	6.3	71.2	84	102	25	113	110+	5.5
S	0.952	275	35	178	94	6.7	33	9.7	35	------	0.07	8.6	5.7	64.8	93	106	20	113	110+	5.8
T	0.960	275	46	300	149	6.0	34	8.3	52	------	0.08	7.5	5.7	68.9	103	102	21	114	110+	0.7
V	0.966	285	52	458	220	5.2	41	7.3	50	----	0.05	7.5	5.7	71.7	85	99	21	113	110+	4.5
X	0.951	250	8	111	63	11.6	23	17.0	40	---	0.06	6.5	6.0	65.6	35	104	21	115	110+	0
Y	0.963	255	21	281	142	9.5	36	14.0	60	----	0.08	8.7	6.6	71.1	25	85	18	116	110+	0
Z	0.972	275	53	613	288	7.0	54	10.2	80	---	0.12	9.3	7.3	76.4	35	86	17	115	110+	0

Identification	Distillation: Initial boiling point, °F.	Total percent off by volume at 500° F.	518° F.	536° F	554° F.	572° F.	590° F	608° F.	626° F.	644° F.	662° F.	680° F.	Total distillate by weight, percent	Loss on cooling, percent by weight	Residue: Float at 122° F., seconds	Residue: Organic matter insoluble in CS_2, percent	Residue: Organic matter insoluble in CCl_4, percent	Distillate: Specific gravity at 77° F.	Distillate: Index of refraction at 77° F.
A	543	-----	-----	------	---	1.0	3.0	6.5	9.5	12.5	15.5	19.3	17.0	4.1	57	0.24	0.47	0.876	1.4889
B	536	----	-----	------	-----	1.5	5.0	8.5	11.8	14.5	17.0	20.0	16.3	4.3	110	0.38	1.83	0.853	1.4714
C	482	3.5	8.5	12.0	15.0	17.5	20.0	22.0	23.5	25.0	26.5	28.0	24.4	1.6	59	---	0.08	0.823	1.4541
D	482	1.0	2.5	5.5	8.5	10.5	12.5	14.0	15.5	16.8	17.5	19.3	16.5	1.2	60	-----	0.09	0.821	1.4529
E	590	-----	-----	-----	-----	-----	-----	---	0.5	1.5	2.8	5.3	4.8	4.3	31	-----	0.08	0.848	1.4680
F	559	-----	-----	-----	-----	-----	-----	---	1.0	3.0	6.0	10.3	9.0	3.0	34	0.20	1.06	0.939	1.5430
G	586	-----	-----	-----	-----	-----	-----	1.5	6.5	12.0	16.0	21.8	19.7	2.8	62	0.29	2.81	0.974	1.5566
H	635	-----	-----	-----	-----	-----	-----	---	---	-----	4.5	10.5	9.3	3.0	75	0.49	3.02	0.983	1.5662
I	599	-----	-----	-----	-----	-----	-----	--	0.5	1.5	4.0	8.3	7.0	2.9	57	0.08	4.54	0.937	1.5364
K	619	-----	-----	-----	-----	-----	-----	--	---	---	2.0	6.0	5.1	3.4	73	0.17	4.46	0.941	1.5410
L	545	-----	-----	-----	-----	1.0	2.0	4.0	6.5	9.0	11.0	14.0	12.9	2.7	51	----	0.04	0.875	1.4771
M	518	-----	-----	0.8	2.5	5.0	7.5	10.0	12.5	14.5	16.5	19.5	17.3	2.8	66	--	0.05	0.861	1.4719
N	546	-----	-----	---	---	----	0.5	1.0	1.5	3.5	5.0	8.3	7.4	3.1	62	--	0.04	0.876	1.4768
O	621	-----	-----	---	---	---	---	--	-	1.5	4.5	8.8	7.9	3.7	30	---	0.06	0.883	1.4852
P	518	-----	-----	---	1.0	3.0	6.0	9.0	12.0	14.5	17.0	20.0	18.0	3.4	82		0.08	0.864	1.4732
R	620	-----	-----	-----	-----	-----	---			1.0	2.0	5.8	5.5	3.9	50	--	0.11	0.873	1.4793
S	567	-----	-----	-----	-----	----	0.5	1.5	3.8	6.5	9.5	13.3	11.8	4.3	46	---	0.13	0.819	1.4676
T	576	-----	-----	-----	-----	-----	-----	1.0	2.5	5.0	7.5	10.8	9.4	4.5	50		0.09	0.849	1.4665
V	600	-----	-----	-----	-----	---	---	--	1.0	2.5	5.0	8.0	7.2	4.6	59	---	0.13	0.850	1.4675
X	543	-----	-----	-----	2.0	6.5	11.5	15.5	19.0	22.0	24.5	27.8	24.2	3.5	101		0.15	0.841	1.4612
Y	500	-----	----	0.5	1.0	2.0	5.0	9.0	12.5	15.5	18.0	21.5	18.8	4.4	122		0.19	0.841	1.4635
Z	564	-----	-----	-----	--	-----	0.5	2.5	6.0	9.0	11.5	14.5	12.2	4.0	123	-	0.14	0.838	1.4626

of loss by weight in the distillation test, and permits a better comparison of the distillation residue with esidues from other tests. The specific gravity of the distillate collected was determined by the pycnometer method. The index of refraction at 77° F. was determined by means of a Zeiss refractometer. The results f the laboratory tests are given in table 3 and when ossible are shown graphically.

The correlation of test data on asphaltic material in eneral, and liquid asphaltic products of the slow-uring type in particular, is made rather difficult ecause of the great variety of petroleums and processes sed in their manufacture. A careful analysis of the ata will be of interest, especially to those who are not amiliar with products from widely different sources.

MATERIALS OF HIGH SPECIFIC GRAVITY SHOW SPECIAL CHARACTERISTICS

In general the test results show that the flash point, consistency, percentage of matter insoluble in naphtha, percentage of fixed carbon and percentage of asphaltic residue of products from the same refinery vary directly as the specific gravity, and the amount of volatile matter varies inversely as the specific gravity. However, these relations are by no means true for the products as a whole. There are certain characteristics which products from different refineries have in common.

Seven of these materials, representing products from four different refineries, have similar characteristics. All have specific gravities greater than 1.000; samples

A and B are only slightly greater, and samples F, G, H, I, and K considerably greater. All of these materials have greater percentages of matter insoluble in naphtha and greater percentages of fixed carbon than the low-gravity products. They are the only materials having an appreciable amount of matter soluble in carbon disulphide but insoluble in carbon tetrachloride (carbenes). Their distillates from the distillation test have high specific gravities and high indexes of refraction. Their asphaltic residues, except those of samples A and B, have the lowest penetrations at 32° F., indicating a high susceptibility to alteration with temperature change and, when tested for ductility at 34–35° F., are brittle and nonductile. Lack of ductility at low temperatures is not, however, a property solely of the asphaltic residues of the high-gravity materials since the residues of some of the low-gravity materials are also non-ductile at 34–35° F. These high-gravity materials are so uniformly different from the other materials included in the series that they are readily identified on most of the graphs as a group.

The results of the consistency tests on the original materials plotted in figure 1, show that the high-gravity materials, except A and B, have lower Furol viscosity values at 140° F. and higher float-test values at 77° F. than the low-gravity materials of the same Furol viscosity at 122° F. It is apparent that the consistencies of these high-gravity materials are more affected by changes in temperature than are the consistencies of the low-gravity materials.

RESULTS OF LABORATORY HEAT TESTS DISCUSSED

Since either 20- or 50-gram samples in tins of standard size are used in the volatilization test, or, as it is sometimes called, the oven test, the materials under investigation were tested by both methods. Figure 2 shows the percentage of loss of 20-gram and 50-gram samples heated for 5 hours at 325° F. and the results of the float test on the residue at 122° F. While the percentage of loss and the float test results on the residues are always higher for the 20-gram samples, there is almost a straight line relation between the percentages of loss and very little relation between the float-test results on the residues.

The results of distillation tests are compared with those from oven tests in figure 3. In the routine performance of the distillation test the percentage of distillate by volume is determined and the volatile matter lost in pouring the residue is not considered. A consistency test on the residue obtained by this method does not represent the consistency of the original material less the volume distilled. Since the weight of distillate lost on cooling was determined, a comparison can be made of the percentage of loss in the volatilization test with the percentage of distillate by volume and with the percentage of total loss in the distillation test by weight, as well as a comparison of the consistencies of the two residues.

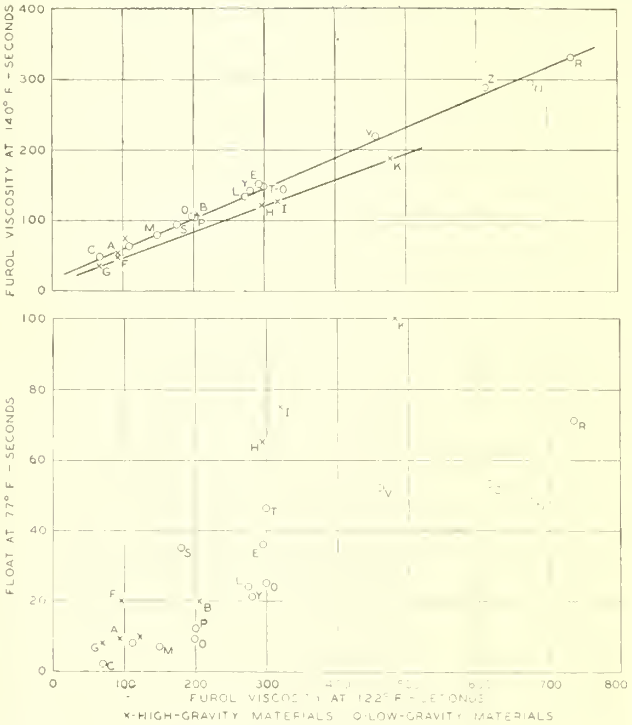

FIGURE 1.—COMPARISON OF RESULTS OF CONSISTENCY TESTS ON ORIGINAL MATERIALS.

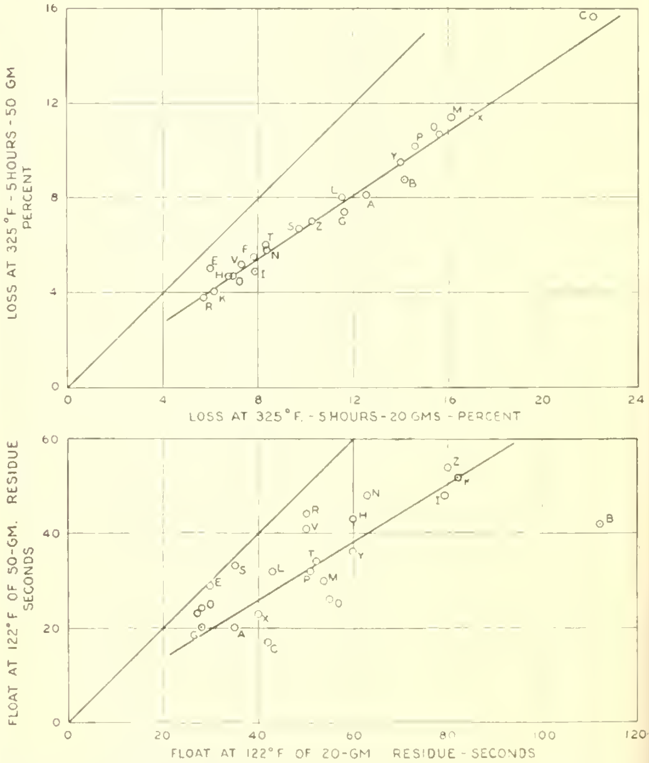

FIGURE 2. COMPARISON OF RESULTS OF VOLATILIZATION TESTS ON 20-GRAM AND 50-GRAM SAMPLES AND RESULTS OF FLOAT TESTS ON RESIDUES.

In figure 3–A, the percentage of distillate by volume is compared with the percentage of loss by weight at 325° F. for 20-gram samples. The percentage of distillate is usually the greater. Since the distillates are of different densities and since the total percentage off at 680° F. does not include the loss on cooling, which is variable, these percentages of volatile matter, one by weight and the other by volume, are not strictly comparable. Therefore, figure 3–B which compares the total percentage of loss by weight in the distillation test with the percentage of loss by weight in the 20-gram volatilization test gives a truer picture of the relationship between the two tests and shows that a greater loss of volatile matter occurs in the distillation test. This is

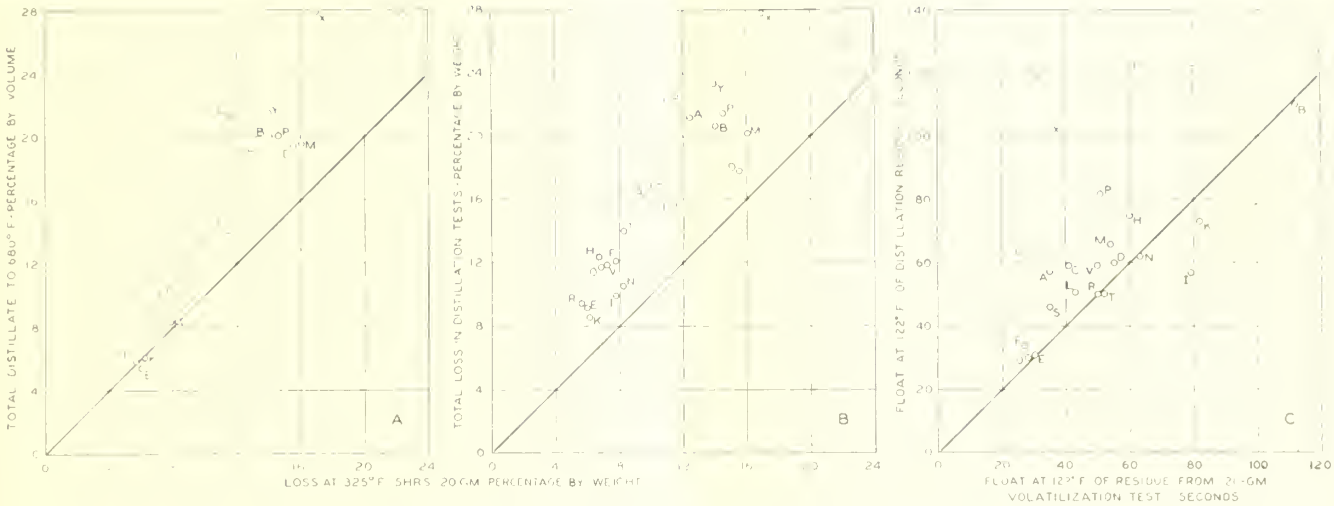

Figure 3.—Comparison of the Percentages of Loss and the Consistencies of the Residues from the 20-Gram Volatilization Test and the Distillation Test.

attributed chiefly to the high temperature to which the distillation test is run and the disturbance of the residue in pouring. Figure 3–C shows that in a few cases the volatilization residue has the higher float-test value, although in general the distillation residue is harder.

The distillation curves of these samples, shown in figure 4, clearly demonstrate that they are composed essentially of high boiling constituents, only samples C and D having distillate boiling under 500° F. All of the curves except those for samples C and D are of the same trend, showing a steady rise from the initial boiling point to the end point of 680° F. The curves for samples C and D, however, begin to flatten out at the higher temperatures, indicating comparatively less material boiling immediately above 680° F. The low loss on cooling which occurred when the residue of these two materials was poured is a further indication that there would be less boiling immediately above 680° F. If these liquid asphaltic products harden only through loss of volatile matter and if the consistency of the distillation residue is representative of the ultimate consistency of the material in service, samples C and D are certainly the most rapid hardening. However, if the ultimate consistency in service is appreciably harder than the consistency of the distillation residues, samples C and D will probably take longer to reach their ultimate consistency than the other materials which do not have such a rapid initial loss of volatile matter.

Both specific gravity determinations and index of refraction determinations were made on the distillates. The gravities and indexes of refraction of the distillate from the high-gravity products are shown in figure 5 to be not only generally higher than the low-gravity products but to fall on different curves, indicating that the chemical structure of the distillates of the high-gravity materials is quite different from that of the distillates of the low-gravity materials.

The asphaltic residue test has been and still is used by many of the States for the control of slow-curing materials. The time of reduction is considered by some as an indication of the relative speed at which the volatile matter is lost. Table 3 shows that the time of reduction varied from 25 minutes for samples K and Y to a maximum of 420 minutes for sample D with an average for the entire group of approximately 95 minutes, although only 5 samples took more than 100 minutes.

FOR SLOW-CURING MATERIALS FROM THE SAME SOURCE, THE PERCENTAGE OF ASPHALTIC RESIDUE VARIES DIRECTLY AS THE VISCOSITY AND INVERSELY AS THE PERCENTAGE OF DISTILLATE

In figure 6 the percentage of asphaltic residue is plotted against the Furol viscosity at 122° F. and the percentage of distillate by volume. While there is again the objection to comparing percentage by volume and percentage by weight, the curves shown would not be materially different if either the percentage of loss in the volatilization test or the total percentage of loss by weight in the distillation test were substituted for the percentage of distillate by volume. Since laboratories using the modified distillation test are reporting percentages by volume, this value is used in the comparison.

For the materials as a group there is no direct relation; but if the results for products from the same refinery are joined by straight lines, it is seen that as the asphaltic residue increases, the viscosity increases and the percentage of distillate decreases. Samples M, P, and B are exceptions to this general rule. Samples M and P were made to meet a specification having an exceptionally low viscosity requirement for a given asphaltic residue and do not correspond with the other samples from the same refinery. These two have properties similar to those of samples X, Y, and Z from another refinery. Sample B, although having a higher asphaltic residue and a higher viscosity than sample A, also has a greater percentage of distillate.

A comparison of the curves of figure 6 shows that for the samples as a whole those products having the lowest viscosity for a given percentage of asphaltic residue generally have the highest percentage of distillate. If the time of float of the distillation residue and the time of reduction to an asphaltic residue of 100 penetration are compared with the positions of the materials in figure 6 it will be seen that, except for samples C and D, those products which have the highest percentage of distillate for a given asphaltic residue have, in general, the highest float of the distillation residue and take the shortest time to come to 100 penetration. However, samples C and D, which the distillation curves show to have high initial volatility, are exceptions to this rule taking by far the longest time for reduction to an asphaltic residue of 100 penetration.

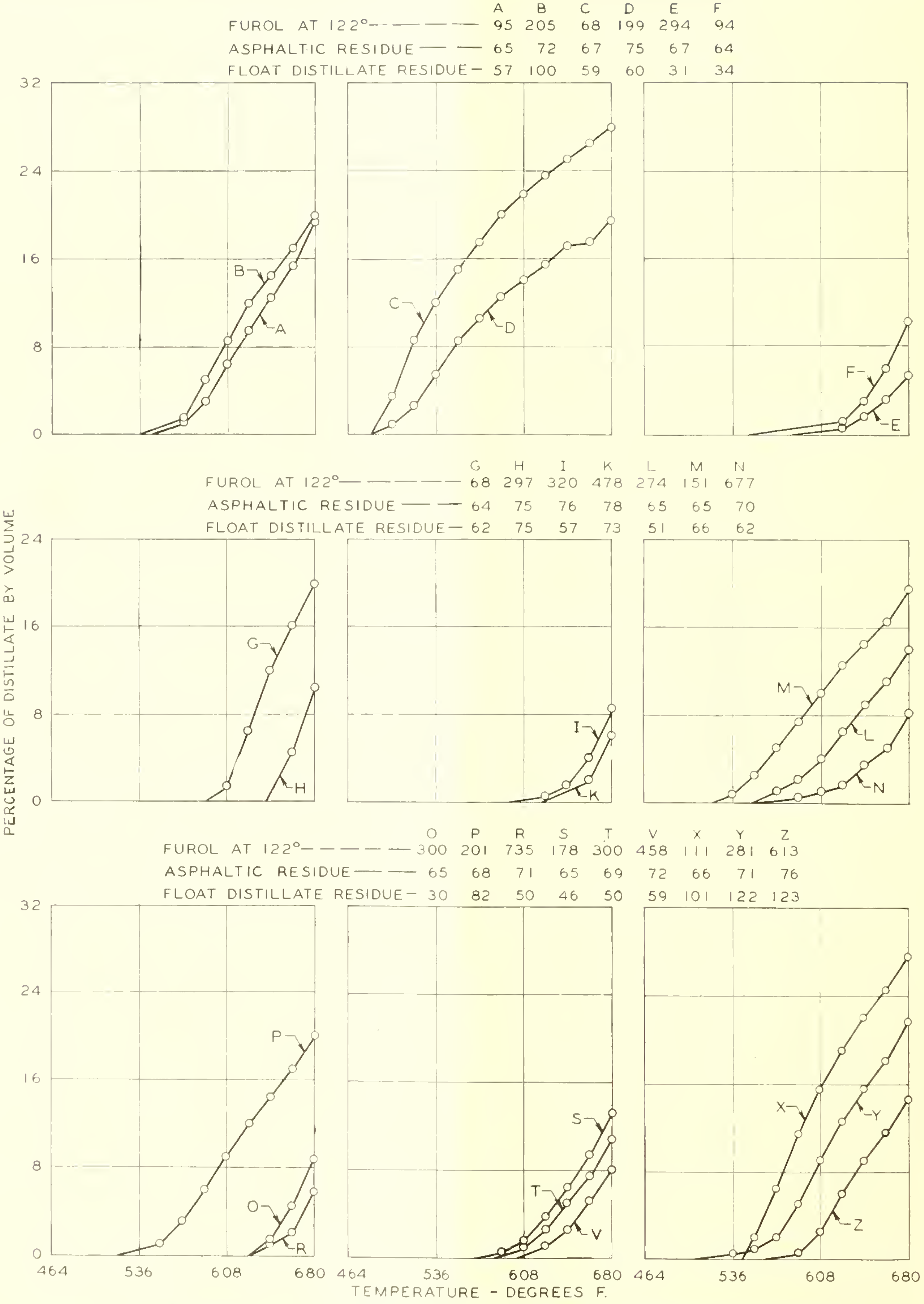

Figure 4.—Relation of Percentage of Distillate by Volume to Distilling Temperature.

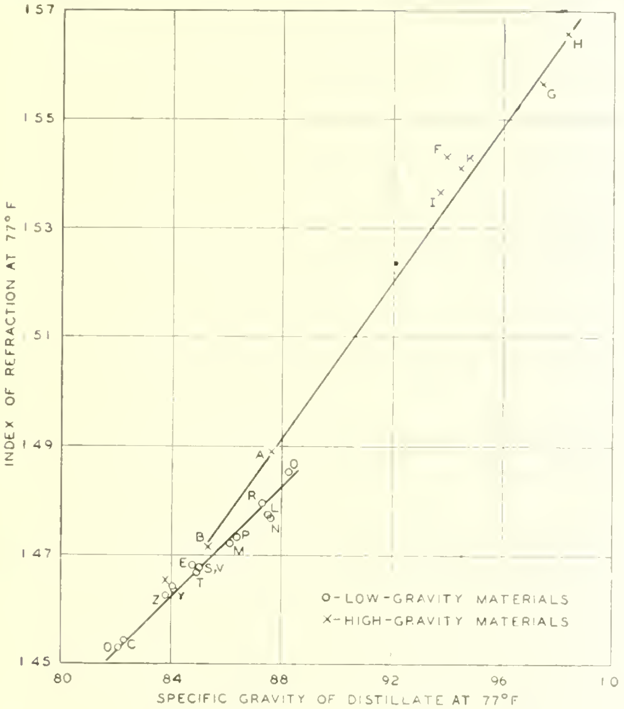

FIGURE 5.—RELATION BETWEEN THE SPECIFIC GRAVITY AND INDEX OF REFRACTION OF THE DISTILLATES.

These products also differ from the others in other respects. Sample D is the only material having a higher percentage of fixed carbon than of asphaltenes in the original material; and the asphaltic residues of both samples C and D have high softening points and penetrations at 32° F.

The test for material insoluble in naphtha and the fixed carbon test are both used as tests of quality and as identification tests. Results of these tests, together with the solubilities in carbon disulphide and carbon tetrachloride, will be discussed in connection with the exposure and laboratory residues.

EXPOSURE OF THIN FILMS OF MATERIAL DESCRIBED

To determine how closely the laboratory evaporation tests indicate the amount of volatile matter lost under actual conditions of exposure and the consistency and character of the resulting residue, relatively thin layers of the materials under investigation were exposed to the action of the sun and air. These samples were not exposed in a manner directly comparable to service conditions, but it is believed that the thicker layers used in this work were not acted upon more severely by the elements than are the relatively thin films of asphaltic materials coating the aggregate in exposed road surfaces. The exposures were made in boxes of the same type as those used in the work of Hubbard and

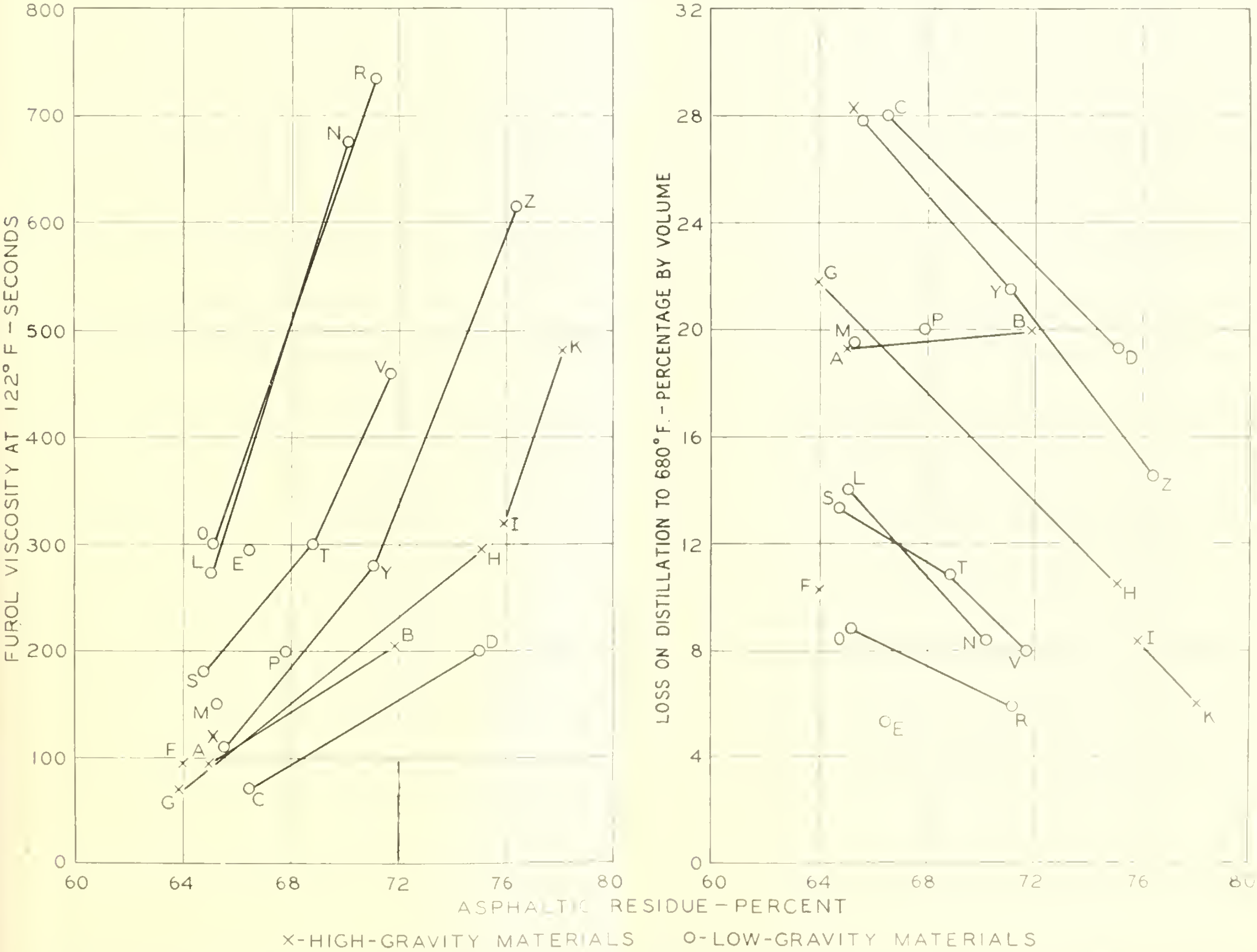

FIGURE 6.—RELATION BETWEEN THE PERCENTAGE OF ASPHALTIC RESIDUE AND THE FUROL VISCOSITY AT 122° F. AND THE PERCENTAGE OF DISTILLATE BY VOLUME.

Reeve,[2] Reeve and Anderton,[3] and Reeve and Lewis.[4] A sketch of the box is shown in figure 7.

These boxes were made of ¾-inch wood and had interior dimensions of 30 by 24 by 3 inches. A plate glass cover resting on strips of felt fastened to the edges of each box made a tight joint and excluded all dust and dirt. A current of air, which had been passed through a wash bottle containing sulphuric acid to remove the dust and eliminate the moisture, was admitted through the bottom of the box and escaped through slots in the side serving to carry off the vapors formed. The slots were protected from the rain by thin boards extending from the top of the box at an angle of about 45°. Cotton batting inserted in the slots excluded dust from the outside air. A thermometer in each box provided a means of determining the temperature which was recorded hourly from 9 a.m. to 4 p.m.

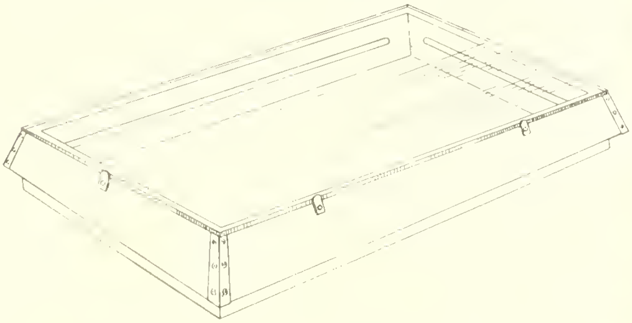

FIGURE 7.—BOX USED IN EXPOSURE TESTS.

The use of plate glass instead of quartz as cover eliminated some actinic rays. This and the absence of moisture probably makes these exposures not fully comparable to outdoor exposure. However, the work of O. G. Streiter [5] shows that a variety of asphalts exhibited the same type of changes when exposed in an accelerated weathering tester as when outdoors under actual weather conditions. It is thought that the presence of water would not have influenced greatly the change in physical and chemical characteristics found in these exposures.

Two samples of each material were placed in seamless, flat bottom tins having a diameter of 5½ inches and a depth of ⅝ inch. Fifty cubic centimeters of material were used to obtain a uniform film or layer thickness of about one-eighth inch (0.128 inch). The samples were so arranged in the exposure boxes and the boxes so placed that no obstruction prevented the action of sunlight. The assembly of the exposure boxes and distributions of samples at start of exposure are shown in figure 8.

The samples were placed in the boxes June 9, 1932, and during the following 15 weeks the minimum and maximum temperatures recorded on the thermometer in the boxes were 60° and 208° F. (9 a.m. to 4 p.m. period only). The average daily minimum and maximum temperatures were 105° and 175° F. The maximum temperature was usually obtained at noon and the minimum in the morning or evening. As the test was conducted to obtain comparative results, the actual temperature of each box is not important as long as all the boxes were at the same temperature. Variations in temperature within the several boxes were slight and could not materially affect the results. The samples were weighed at intervals and the percentage of loss calculated. One set was removed for test at the end of 10 weeks and the other at the end of 15 weeks. The percentage of loss at the different stages of the exposures are shown in table 4. The surface conditions of the various materials at the end of 15 weeks exposure are shown in figures 9, 10, 11, and 12.

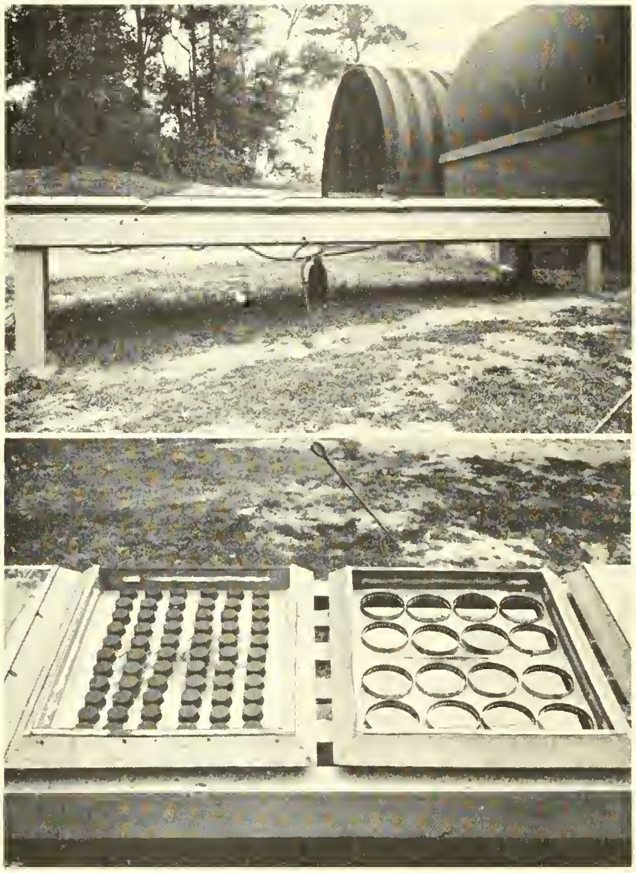

FIGURE 8.—THIN FILMS OF SLOW-CURING MATERIAL AND SPECIMEN CYLINDERS EXPOSED TO SUN.

O. G. Streiter, in studying the progress of the deterioration in asphalts on weathering, resorted to the determination of the oils, resins, and asphaltenes, according to the scheme of Marcusson. The deterioration is shown by a decrease in oils and resins and an increase in asphaltenes. Hubbard and Reeve resorted to consistency tests and tests of solubility in naphtha and carbon disulphide. Reeve and Lewis used these and the softening-point determination and the fixed-carbon test to show the changes which had occurred in terms generally used in routine asphalt testing. The residues after 10 and 15 weeks of exposure were subjected to the tests used by Hubbard and Reeve and Reeve and Lewis, and also to determinations of specific gravity, ductility at two temperatures, and solubility in carbon disulphide and carbon tetrachloride.

In order to compare the residues after exposure in all particulars with the residues developed in the accelerated laboratory tests, the laboratory residues from the 20-gram volatilization test, the distillation

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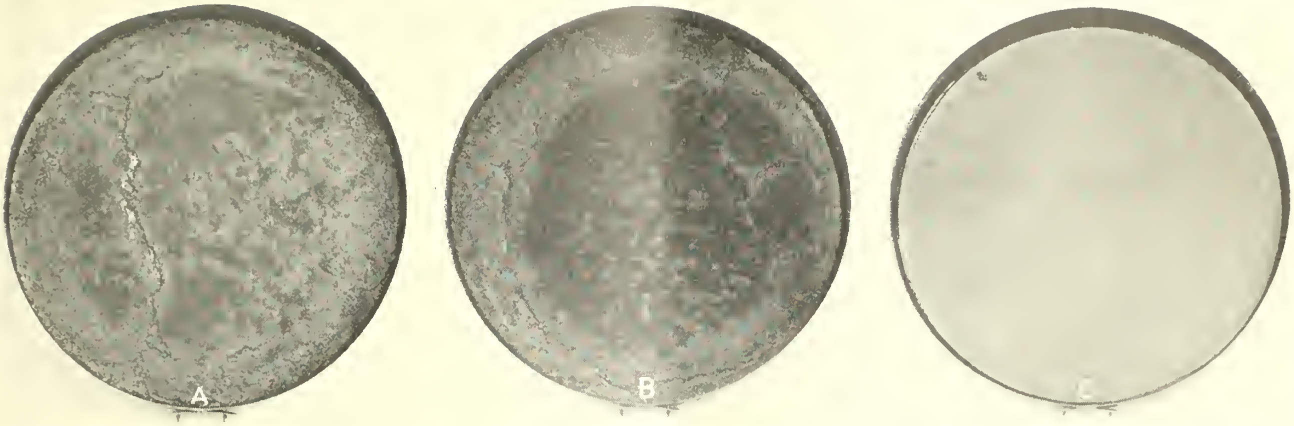
[2] The Effect of Exposure on Bitumens. Jour. Industrial and Engineering Chemistry, vol. 5, (1913) 5. A paper presented at Eighth International Congress of Applied Chemistry.

[3] The Effect of Exposure on Tar Products. Jour. Franklin Institute, October, 1916.

[4] The Effect of Exposure on Some Fluid Bitumens. Jour. Industrial and Engineering Chemistry, vol. 9, no. 8, p. 743.

[5] Accelerated Tests of Asphalts, Bureau of Standards Journal of Research, vol. 5, August 1930.



Major portion of the surface is dull, black, and pitted. Surface has shrunk and cracked. Material in bottom of large crack is soft and sticky. Remaining surface is very hard.

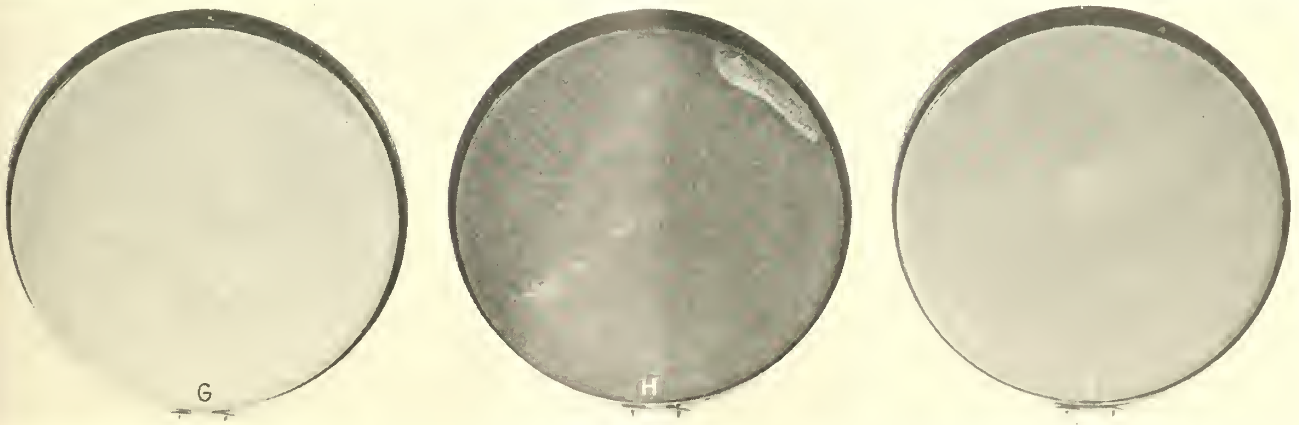
Major portion of the surface is dull, black, and pitted. Surface has shrunk and cracked. Material in bottom of larger cracks is soft and sticky. Remaining surface is very hard.

Surface is smooth and glossy to the naked eye but has a mottled appearance when seen under a glass. There is an indication of checking

Surface is smooth and glossy to the naked eye but has a mottled appearance when seen under a glass. There is an indication of checking.

Surface is dull and mottled except for a small scaly area, caused by material drawing.

Surface glossy and sticky

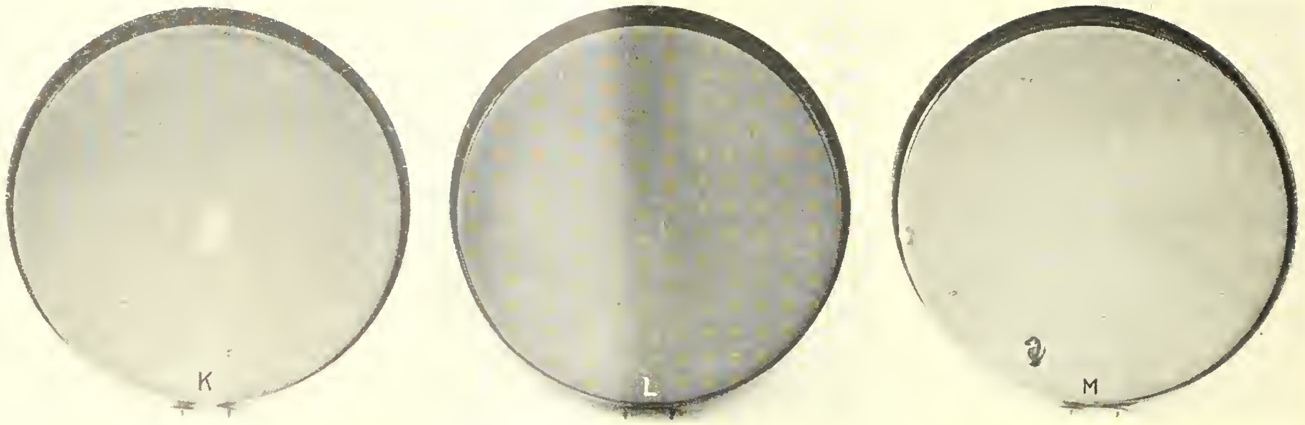


Surface mottled and iridescent; has a greasy feeling.

Surface mottled and iridescent; has a greasy feeling.

Surface highly iridescent; has a greasy feeling. Has a fine needlelike appearance under a glass.

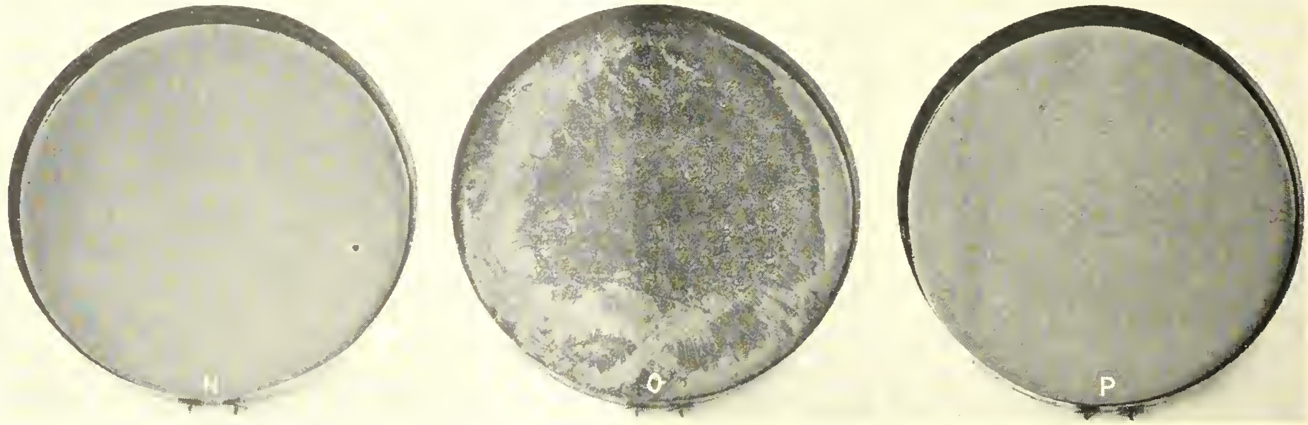
Figure 9.—Surface Condition of Exposed Films at End of 15 Weeks.



Surface highly iridescent; has a greasy feeling. Has a fine needlelike appearance under a glass.

Surface smooth and glossy to the naked eye, but appears drawn when seen under a glass. Surface sticky.

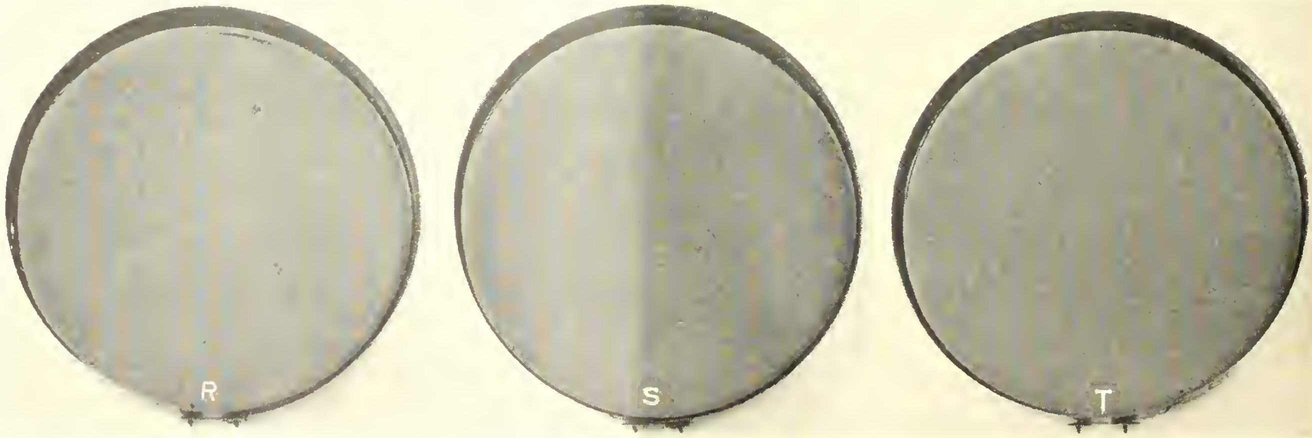
Surface smooth and glossy to the naked eye, but appears drawn when seen under a glass. Surface sticky.



Surface smooth and glossy to the naked eye, but appears drawn when seen under a glass. Surface sticky.

Surface rough and pitted, and black and glossy. Surface around outer edge shows few smooth glossy spots. There is extreme drawing in some areas.

Surface smooth and glossy to the naked eye, but appears drawn when seen under a glass. Surface sticky.

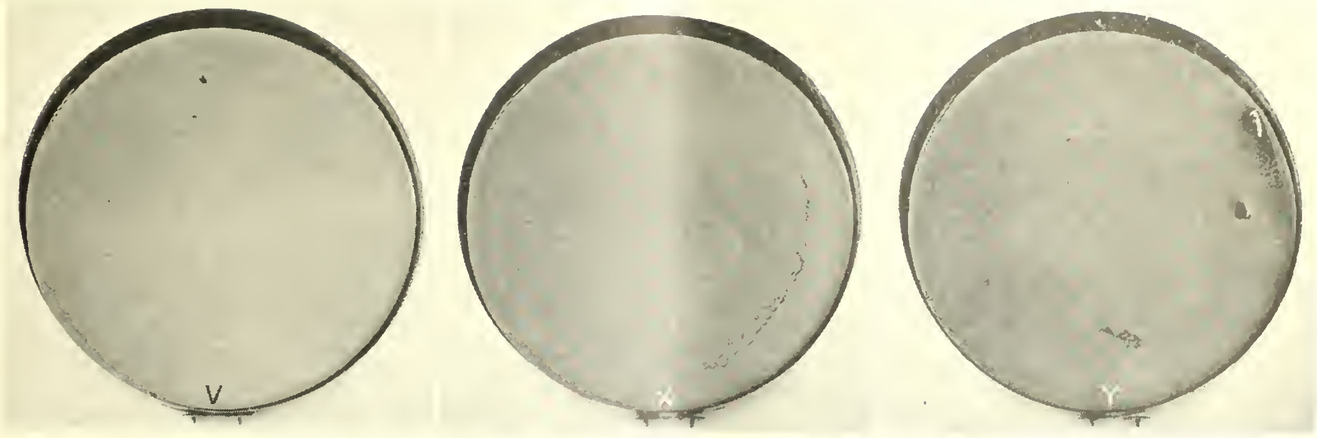


Surface smooth and glossy to the naked eye, but appears drawn when seen under a glass. Surface sticky.

Surface smooth and glossy; appears slightly drawn when seen under a glass.

Surface smooth and glossy; appears slightly drawn when seen under a glass.

FIGURE 10.—SURFACE CONDITION OF EXPOSED FILMS AT END OF 15 WEEKS.



Surface smooth, glossy, and sticky.

Surface glossy, with a network of checking over most of surface.

Surface smooth and glosssy, with a network of checking over most of surface

Figure 11.—Surface Condition of Exposed Films at End of 15 Weeks.

Surface glossy and slightly drawn. Some checking over most of surface.

igure 12.—Surface Condition of Exposed Film at End of 15 Weeks.

est and the asphaltic-residue test were subjected to he same tests made on the residues after exposure. he results of the tests on both the laboratory residues nd residues after exposure are given in table 5.

OSSES IN DISTILLATION TEST MOST NEARLY APPROXIMATE LOSSES RESULTING FROM EXPOSURE

An examination of table 4 shows that all of the aterials lose in weight rather rapidly at first and more lowly as the time of exposure increases. There is, owever, a great deal of difference in the rate of loss. f the loss in weight at the end of the 15-week period s considered as the maximum possible loss under onditions of this test, then in 2 days the exposure amples lose from 13 percent (sample H) to 61 percent sample C) of their volatile matter; in 12 days they se from 21 percent (sample G) to 74 percent (sample C); and in 35 days from 68 percent (sample G) to 95 percent (sample D). Samples C, D, and M lost 48 percent or more of their volatile matter in 2 days while none of the other samples lost more than 35 percent. These three samples likewise lost a greater percentage of their volatile matter in 12 and 35 days than the other materials. At the end of 10 weeks all of the samples had lost at least 87 percent of their volatile matter and all but 6 had lost over 95 percent. It is reasonable to suppose that the losses at the end of a 15-week period would not have been increased materially had the exposure continued for a longer time.

Table 4.—*Rate of loss in thin film exposure*

Identification	Percentage loss of bitumen					
	Time of exposure—days					
	2	12	35	50	70	105
A	4.2	6.9	11.1	15.5	16.9	18.2
B	6.5	9.4	16.0	17.4	18.9	19.8
C	16.4	20.0	25.1	25.6	26.3	26.9
D	10.0	12.9	17.8	18.2	18.6	18.7
E	2.7	3.5	6.7	7.3	8.6	8.3
F	3.3	4.8	11.5	12.7	14.1	16.0
G	3.6	5.0	16.2	18.9	22.1	23.7
H	2.1	4.0	11.7	13.3	15.0	16.3
I	2.8	4.0	9.9	11.3	13.1	13.7
K	2.3	3.4	8.1	9.4	10.9	11.5
L	4.3	6.7	13.5	14.6	15.7	17.7
M	9.9	11.5	18.4	19.1	20.2	20.1
N	2.5	3.7	9.3	10.1	11.3	11.9
O	2.6	3.9	9.2	10.2	11.1	11.5
P	7.3	11.0	18.5	19.9	22.4	22.6
R	2.0	2.6	7.1	8.1	9.3	9.5
S	3.4	5.0	12.3	13.5	14.8	17.1
T	2.5	3.8	10.3	11.6	13.2	13.7
V	4.1	5.0	9.1	10.3	11.5	11.8
X	8.4	13.8	24.1	25.6	27.1	27.9
Y	6.6	10.1	19.3	20.5	21.6	22.5
Z	3.3	5.9	11.1	15.2	16.5	17.0

Figure 13 is a comparison of the 15 weeks' exposure losses and the losses occurring in the laboratory control tests. The percentage of loss in the 15 weeks' exposure is about the same as the total loss in the distillation test, about 1½ times as great as the loss in the 20-gram volatilization test and twice as great as the loss in the 50-gram volatilization test. When the exposure losses are compared with the losses in the asphaltic residue test, however, no reasonably consistent relation is found. The losses in the 15-week exposure samples vary from one-fourth of the loss occurring in the asphal-

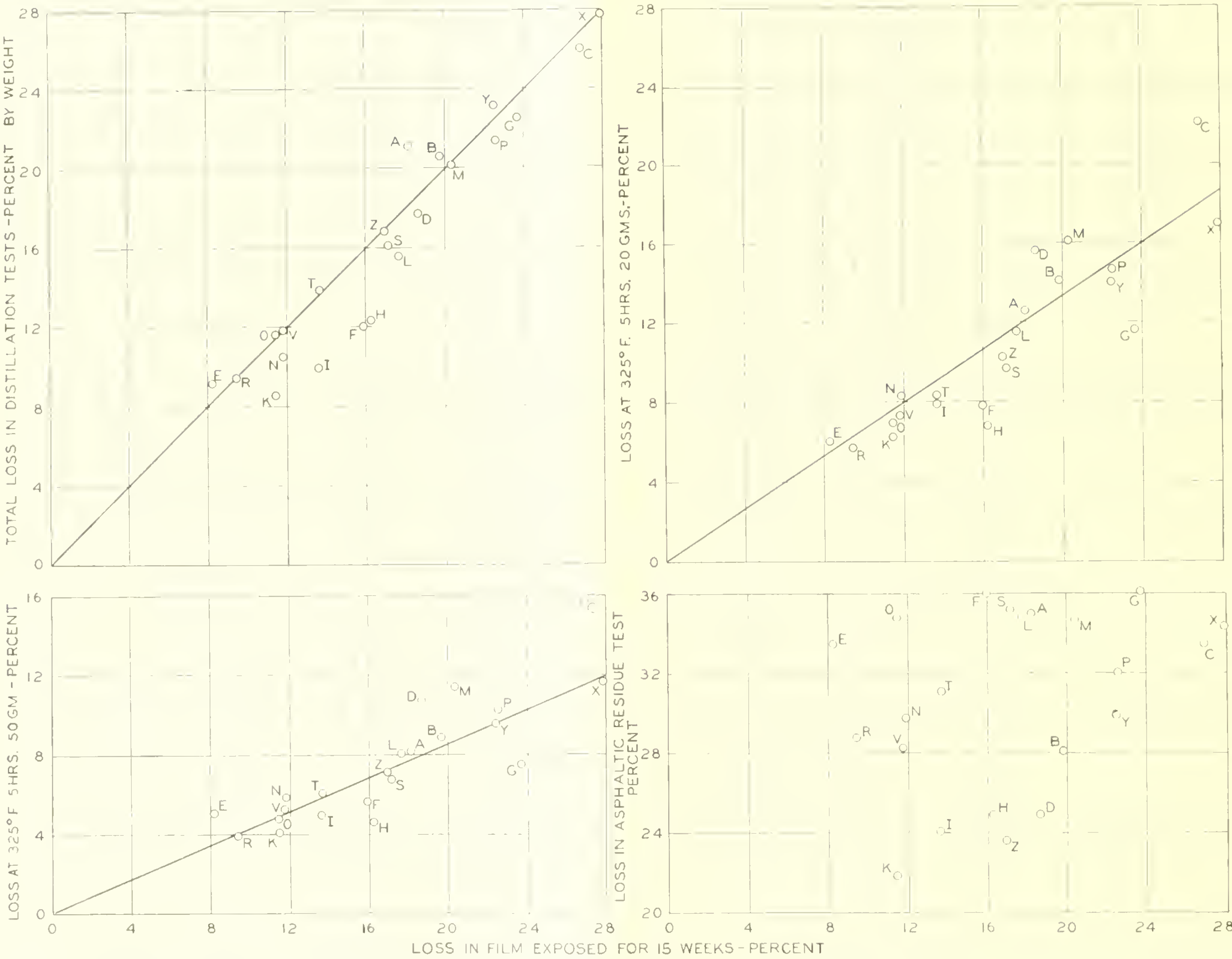


Figure 13.—Comparison of the Percentage of Loss After 15 Weeks of Exposure With Loss in the Laboratory Evaporation Tests.

tic residue test for sample E to four-fifths of the loss occurring in the asphaltic residue test on sample X, with an average for the entire group of slightly over one-half of the loss which takes place when these liquid asphaltic materials are reduced to asphaltic residues of 100 penetration by the usual laboratory methods.

The comparisons show that the total loss by weight in the distillation test (including loss on cooling) more nearly approximates the ultimate loss which occurs when these materials are exposed under the conditions of this test than do the losses which occur in the volatilization or asphaltic residue tests.

The losses in the various laboratory and exposure tests are of importance when comparisons are made of the consistencies of the residues as given in table 5. Although the losses in the distillation test and the 15-week exposure test are about equal the distillation residues are fluid and the exposure residues are semisolid. In spite of the fact that the losses in the exposure test are considerably less than the losses in the asphaltic residue test, the exposure residues are in all but two cases (samples D and E) harder than the corresponding asphaltic residues and in those cases the exposure residues were comparable to an asphaltic residue of 100 penetration.

MATERIALS HIGHLY ALTERED BY EXPOSURE

Bituminous materials upon exposure undergo changes which are due to something more than mere loss of volatile matter. This has been discussed in the papers referred to on page 92 and is demonstrated by these tests. Reeve and Lewis showed that, for equivalent losses, atmospheric exposed samples developed harder consistencies than 20-gram volatilization samples. In the present investigation the exposed samples produced residues much harder than the distillation residues and, in all except two cases, harder than the asphaltic residues although the loss in the exposure test was about the same as the loss in the distillation test and much less than the loss in the asphaltic residue test.

A study of the characteristics of the residues after exposure and the asphaltic residues produced under laboratory conditions is of interest. It has been demonstrated that when asphaltic materials are subjected to high temperatures such as are reached in the asphaltic residue test, they are highly susceptible to oxidation, producing chemical reactions which result in artificial hardening of the material. Bateman and Delp[6] showed that when Mexican asphalt is sprayed on hot

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[6] The Recovery and Examination of the Asphalt in Asphaltic Mixtures, Proc A.S.T.M., vol. 27, pt. 2, p. 465.

TABLE 5.—*Tests on laboratory and exposure residues*

Identification	Volatilization residue						Distillation residue						Asphaltic residue										
		Tests on residue						Tests on residue						Tests on residue									
	Loss at 325° F., 20 grams, 5 hours, percent	Float at 122° F., seconds	Organic matter insoluble in CS_2, percent	Organic matter insoluble in CCl_4, percent	Organic matter insoluble in 86° B. naphtha, percent	Fixed carbon, percent	Loss to 680° F., total percent by weight	Float at 122° F., seconds	Organic matter insoluble in CS_2, percent	Organic matter insoluble in CCl_4, percent	Organic matter insoluble in 86° B. naphtha, percent	Fixed carbon, percent	Loss on heating at 480-500° F., percent	Specific gravity at 77° F.	Penetration at 77° F., 100 grams, 5 seconds	Penetration at 32° F., 200 grams, 60 seconds	Softening point, ° F.	Ductility at 77° F., 5 centimeters per minute	Ductility at 34-35° F., 5 centimeters per minute	Organic matter insoluble in CS_2, percent	Organic matter insoluble in CCl_4, percent	Organic matter insoluble in 86° B. naphtha, percent	Fixed carbon, percent
A	12.5	35	0.39	1.33	16.5	11.2	21.1	57	0.24	0.47	16.9	11.7	35.0	1.059	87	19	113	110+	0	0.39	1.46	25.8	17.6
B	14.1	112	0.28	4.88	23.3	14.7	20.6	110	0.38	1.83	21.3	15.4	28.1	1.081	81	15	114	110+	0	0.60	3.41	29.2	17.6
C	22.1	42	......	0.05	9.7	8.7	26.0	59	......	0.08	9.2	8.9	33.5	1.008	95	25	118	110+	4.8	......	0.19	19.9	12.7
D	15.6	55	......	0.02	8.8	8.6	17.7	60	......	0.09	7.2	8.6	24.9	1.010	88	27	120	110+	4.8	......	0.15	18.5	12.7
E	6.0	30	......	0.04	13.0	8.7	9.1	31	......	0.08	11.6	8.8	33.5	1.023	104	30	114	110+	6.0	......	0.13	24.4	13.9
F	7.8	27	0.10	1.73	20.1	10.2	12.0	34	0.20	1.06	21.1	10.4	36.0	1.122	101	9	108	110+	0	0.75	3.12	38.9	15.7
G	11.6	28	0.95	4.95	25.0	12.8	22.5	62	0.29	2.84	30.0	14.4	36.1	1.141	82	8	109	110+	0	0.71	4.98	38.7	18.7
H	6.8	60	1.84	5.68	29.9	14.6	12.3	75	0.49	3.02	31.1	15.1	24.9	1.143	92	8	109	110+	0	1.00	4.02	36.8	18.1
I	7.9	79	0.69	7.35	31.4	16.9	9.9	57	0.08	4.54	35.2	16.4	24.1	1.128	92	11	109	110+	0	0.24	3.81	39.4	19.4
K	6.2	82	0.47	6.70	30.5	16.8	8.5	73	0.17	4.46	37.0	16.3	21.9	1.128	100	14	108	110+	0	0.30	5.21	37.8	19.4
L	11.5	43	......	0.07	8.9	5.5	15.6	51	......	0.04	6.8	5.4	34.9	1.016	93	20	111	110+	0	......	0.11	19.0	9.3
M	16.1	54	......	0.09	10.6	6.3	20.1	66	......	0.05	8.2	6.3	34.7	1.018	112	19	110	110+	0	......	0.08	17.4	9.2
N	8.3	63	......	0.06	8.7	6.0	10.5	62	......	0.04	7.0	5.7	29.8	1.016	105	19	109	110+	0	......	0.09	15.3	8.6
O	6.9	28	......	0.06	11.3	5.8	11.6	30	......	0.06	8.9	5.9	34.8	1.016	101	26	113	110+	5.8	......	0.14	23.1	10.0
P	14.6	51	......	0.07	12.5	7.1	21.4	82	......	0.08	9.4	7.3	32.1	1.017	107	18	110	110+	1.0	......	0.07	17.1	9.2
R	5.7	50	......	0.09	12.7	6.7	9.4	50	......	0.11	10.7	6.6	28.8	1.017	102	25	113	110+	5.5	......	0.08	20.5	9.7
S	9.7	35	......	0.11	12.2	6.4	16.1	46	......	0.13	10.5	6.5	35.2	1.021	106	20	113	110+	5.8	......	0.09	21.2	9.9
T	8.3	52	......	0.12	11.1	6.4	13.9	50	......	0.09	9.5	6.4	31.1	1.009	102	21	114	110+	0.7	......	0.04	19.5	9.9
V	7.3	50	......	0.13	10.9	6.3	11.8	59	......	0.13	9.1	6.4	28.3	1.006	99	21	113	110+	4.5	......	0.05	18.7	9.4
X	17.0	40	......	0.12	12.1	7.2	27.7	101	......	0.15	10.9	7.7	34.4	1.016	104	21	115	110+	0	......	0.15	15.1	9.1
Y	14.0	60	......	0.14	12.8	7.6	23.2	122	......	0.19	12.6	8.3	28.9	1.023	85	18	116	110+	0	......	0.08	15.5	9.6
Z	10.2	80	......	0.08	13.2	8.1	16.8	123	......	0.14	12.8	8.5	23.6	1.018	86	17	115	110+	0	......	0.11	17.4	10.0

Identification	10-week exposure residue										15-week exposure residue										
		Tests on residue										Tests on residue									
	Loss, percent	Penetration at 77° F., 100 grams, 5 seconds	Penetration at 32° F., 200 grams, 60 seconds	Softening point, ° F.	Ductility at 77° F., 5 centimeters per minute	Ductility at 34-35° F., 5 centimeters per minute	Organic matter insoluble in CS_2, percent	Organic matter insoluble in CCl_4, percent	Organic matter insoluble in 86° B. naphtha, percent	Fixed carbon, percent	Loss, percent	Specific gravity at 77° F.	Penetration at 77° F., 100 grams, 5 seconds	Penetration at 32° F., 200 grams, 60 seconds	Softening point, ° F.	Ductility at 77° F., 5 centimeters per minute	Ductility at 34-35° F., 5 centimeters per minute	Organic matter insoluble in CS_2, percent	Organic matter insoluble in CCl_4, percent	Organic matter insoluble in 86° B. naphtha, percent	Fixed carbon, percent
A	16.0	115	34	149	3	0.5	0.87	3.49	30.0	14.9	18.2	1.066	46	20	172	0.5	0	1.61	4.25	34.1	16.1
B	18.3	41	17	163	1	0	1.06	8.27	34.8	18.3	19.8	1.084	19	12	181	0.3	0	2.50	9.11	37.2	19.6
C	26.1	117	38	111	72	4.3	......	0.15	19.3	9.8	26.9	1.012	74	26	119	74	3	......	0.10	21.1	10.8
D	18.5	132	37	106	110+	1.5	......	0.10	17.6	9.5	18.7	1.013	93	29	113	86	4	......	0.17	19.6	10.6
E	9.1	215	69	105	68	5.3	......	0.07	25.0	11.1	8.3	1.014	124	52	117	23	3.3	......	0.11	27.3	11.1
F	14.2	234	32	92	68	20.0	2.54	8.15	34.6	15.2	16.0	1.090	79	12	109	100	0	3.69	9.59	36.7	16.0
G	22.2	119	23	103	110+	0.5	5.10	12.22	35.7	19.4	23.7	1.104	55	14	115	110+	0	6.56	14.79	37.6	20.4
H	14.9	76	13	110	110+	0	4.14	11.78	40.0	19.9	16.3	1.152	37	8	120	110+	0	6.41	13.40	41.5	21.8
I	13.3	40	9	121	110+	0	5.96	14.94	41.1	21.5	13.7	1.133	28	8	129	110+	0	6.17	15.61	38.8	22.3
K	11.2	48	11	118	110+	0	4.51	14.66	40.0	21.3	11.5	1.131	32	6	126	110+	0	5.41	15.25	39.1	21.9
L	14.7	257	67	91	85	5.6	......	0.15	19.9	7.0	17.7	1.020	87	25	113	110+	4.5	......	0.10	24.7	8.2
M	20.0	111	31	109	110+	5.8	......	0.09	22.1	8.5	20.4	1.023	72	22	118	110+	4.0	......	0.11	25.0	9.0
N	11.2	146	35	103	110+	8.0	......	0.15	20.7	7.5	11.9	1.019	91	25	113	110+	4.8	......	0.09	23.8	8.6
O	11.3	60	31	131	10	1.8	......	0.16	29.5	7.9	11.5	1.020	40	23	144	3.8	0.3	......	0.37	33.2	9.1
P	20.7	85	23	113	110+	4.3	......	0.10	23.3	8.8	22.6	1.027	38	12	128	110+	0	......	0.17	28.4	10.3
R	9.7	86	28	113	102	3.8	......	0.12	30.5	8.1	9.5	1.019	57	23	124	68	2.8	......	0.15	30.4	9.3
S	14.6	142	45	108	60	3.0	......	0.07	25.8	7.3	17.2	1.001	83	31	120	22	2.5	......	0.11	28.4	9.1
T	13.1	95	30	115	65	3.3	......	0.05	26.8	7.8	13.7	1.000	67	24	121	42	1.3	......	0.14	28.5	9.0
V	11.4	105	29	112	81	3.8	......	0.10	25.5	7.7	11.8	1.008	68	23	120	34	2.5	......	0.12	28.2	9.0
X	27.4	45	12	125	110+	0	......	0.15	21.9	9.1	27.9	1.023	30	10	133	59	0	......	0.13	29.4	10.9
Y	21.2	55	15	121	92	0	......	0.09	23.6	9.1	22.5	1.023	29	10	132	74	0	......	0.09	28.4	10.7
Z	16.4	47	12	125	110+	0	......	0.14	23.2	9.6	17.0	1.023	29	9	133	25	0	......	0.11	28.8	11.4

sand in the usual mixing process under normal paving practice the softening point is increased, the penetrations at low and high temperatures are more closely drawn together and the ductility of the material is greatly reduced. It was the authors' conclusion that because of the great surface area of hot asphalt exposed to the air on the surface of the mineral aggregate, there was an excellent opportunity for oxidation.

In table 6 the asphaltic residues are compared with the residues of approximately the same consistency obtained in the exposure test. Seven of the residues of exposed samples were considerably harder than 100 penetration at the end of 10 weeks and are not included in the table. The softening points, penetration ratios and ductilities shown in the table indicate that the residues after exposure are more highly oxidized than the corresponding asphaltic residues.

The softening points of the residues after exposure are not strikingly different from the softening points of laboratory-produced residues except in the case of sample A. The ratio of penetration at 77° F. to penetration at 32° F. is always greater for the asphaltic residues than for the residues after exposure. This shows the lower susceptibility of the latter residues to temperature change, which is a characteristic of oxidized asphalts. The ductility at 77° F. of the asphaltic residues is 110+, but the ductility of the residues after exposure at 77° F. in 6 samples has been materially

Table 6.—*Comparison of residues of approximately 100 penetration obtained from the asphaltic residue test and from exposed films of material*

Identification	Asphaltic residue: Penetration At 77° F.	Asphaltic residue: Penetration At 32° F.	Asphaltic residue: Ratio penetration at 77° F. to penetration at 32° F.	Asphaltic residue: Softening point ° F.	Asphaltic residue: Ductility At 77 F.	Asphaltic residue: Ductility At 34–35° F.	Exposure residue: Penetration At 77° F.	Exposure residue: Penetration At 32° F.	Exposure residue: Ratio penetration at 77° F. to penetration at 32° F.	Exposure residue: Softening point ° F.	Exposure residue: Ductility At 77° F.	Exposure residue: Ductility At 34–35° F.	Time of exposure—weeks
A	87	19	4.6	113	110+	0	115	34	3.4	149	3	0.5	10
C	95	25	3.8	118	110+	4.8	117	38	3.1	111	72	4.5	10
D	88	27	3.3	120	110+	4.8	93	29	3.2	113	86	4	15
E	104	30	3.5	114	100+	6.0	124	52	2.4	117	23	3.3	15
F	101	9	11.2	108	110+	0	79	12	6.6	109	100	0	15
G	82	8	10.2	109	110+	0	119	23	5.2	103	110+	0	10
H	92	8	11.5	109	110+	0	76	13	5.9	110	110+	0	10
L	93	20	4.7	111	110+	0	87	25	3.5	113	110+	4.5	15
M	112	19	5.9	110	110+	0	111	31	3.7	109	110+	5.8	10
N	105	19	5.5	109	110+	0	91	25	3.7	113	110+	4.8	15
P	107	18	6.0	110	110+	1.0	85	23	3.7	113	110+	4.3	10
R	102	25	4.1	113	110+	5.5	86	28	3.1	113	102	3.8	10
S	106	20	5.3	113	110+	5.8	83	31	2.7	120	42	1.3	15
T	102	21	4.9	114	110+	0.7	95	30	3.2	115	60	3.3	10
V	99	21	4.7	113	110+	4.5	105	29	3.6	112	81	3.8	10

lowered and, in the case of sample A, an extremely nonductile residue has been produced. Materials which are highly ductile at 77° F. generally have little if any ductility at low temperatures and in the case of samples L, M, and N, the fact that the residues after exposure have a higher ductility at 34-35° F. than the corresponding asphaltic residues may be due to the fact that the residues after exposure may actually have a lesser ductility at 77° F. than the asphaltic residues. This difference, if it exists, is not shown by the test results because of the limited capacity of the ductility machine available.

The softening point of the residues after exposure of samples B and O, although not shown in table 6 because of their low penetrations at the end of 10 weeks, are also abnormally high when compared with other residues having practically the same consistency. The ductility of the residues after exposure of these two samples is also exceedingly low. It will be shown later by other tests that there are changes in characteristics in the asphaltic residues which may be attributed to oxidation. Nevertheless, from a study of these data it is apparent that the effects of oxidation at comparatively low temperatures over a relatively long period of time are more pronounced than at high temperatures for a comparatively short period.

Attention is called to the behavior of samples A, B, and O. It has been held by some authorities that liquid asphaltic materials which give ductile residues are desirable materials for road use and that products giving non-ductile residues are unsuitable for many types of road construction. While producing a residue of satisfactory properties in the asphaltic residue test, samples A, B, and O, on exposure, lost practically all ductility and were materially altered as shown by their photographs in figures 9 and 10. From the standpoint of surface appearance these samples are the worst of the group.

CONSIDERABLE FIXED CARBON AND MATERIAL INSOLUBLE IN NAPHTHA FORMED IN ALL MATERIALS DURING EXPOSURE

Since both the percentage of material insoluble in naphtha and the percentage of fixed carbon are considered to be characteristic of the source and method of manufacture of different types of asphaltic materials, the relations between these two values for the original materials and all of their residues are plotted in figure 14. Only a very general relation is indicated for the

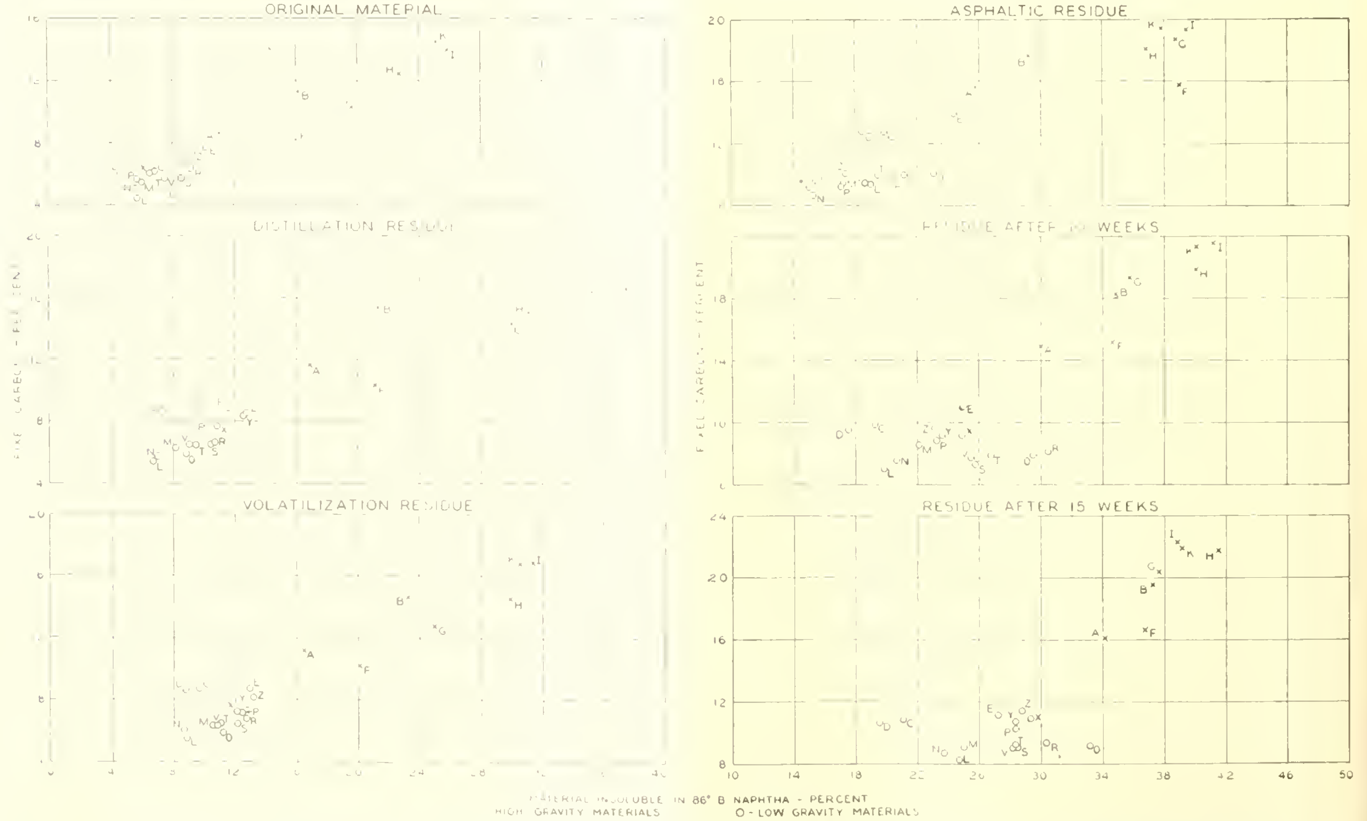

Figure 14.—Relation Between the Percentage of Fixed Carbon and Material Insoluble in Naphtha in the Original Materials and Their Residues Resulting from Laboratory Treatment and Field Exposure.

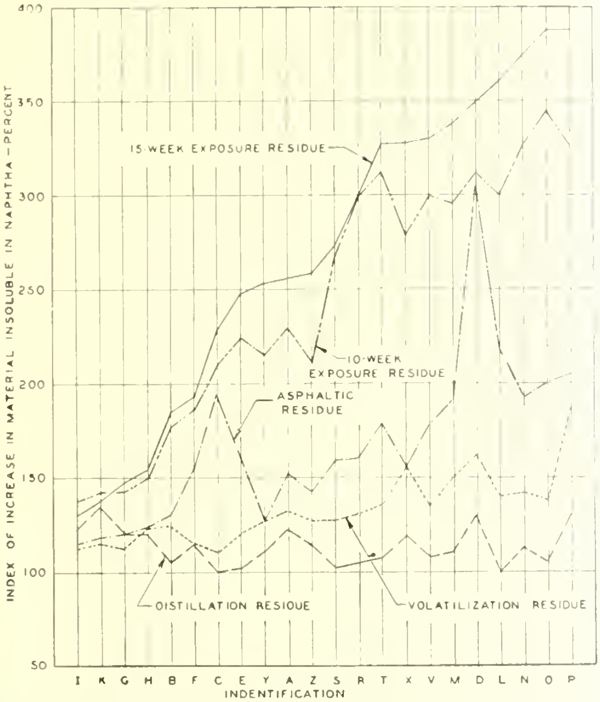

FIGURE 15.—INDEX OF INCREASE IN MATERIAL INSOLUBLE IN NAPHTHA IN THE VARIOUS RESIDUES.

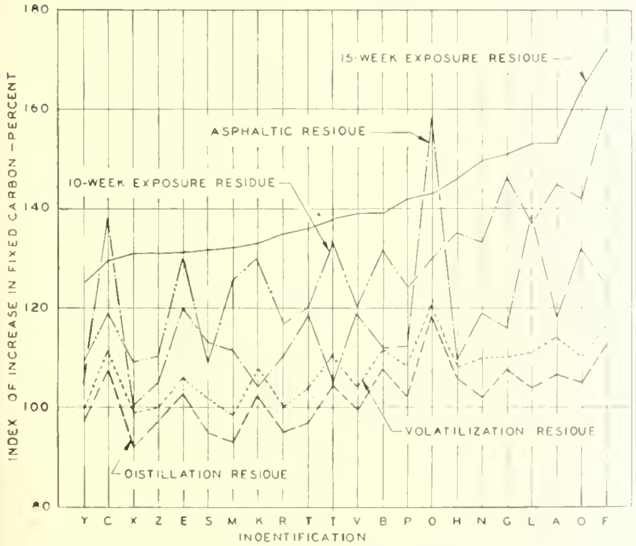

FIGURE 16.—INDEX OF INCREASE IN FIXED CARBON IN THE VARIOUS RESIDUES.

group as a whole. However, in all cases the high-gravity materials have higher percentages of fixed carbon and material insoluble in naphtha than the low-gravity materials. It is of interest to note that materials from the same refinery, and presumably from the same source, continue to show the same relations in the residues as in the original material (samples C, D, S, T, and V).

Anderton[7] found that in the steam distillation of petroleums from various fields the fixed carbon of a residue is dependent only upon the character of the crude material and is unaffected by the distillation. Within the limits of accuracy of the test, the fixed carbon value for any residue can therefore be readily calculated by knowing the fixed carbon of the original material and the percentage of distillate driven off during the steam distillation. He also found that the percentage of asphaltenes increased in the various residues obtained in fractional steam distillation in greater proportion than could be attributed to loss of volatile matter and concluded that there were changes occurring which resulted in the actual formation of bodies of an asphaltic character.

This later work of Anderton justified to a great extent the use of the fixed carbon and naphtha-solubility tests by Reeve and Lewis in studying the effects of exposure on asphaltic materials. The latter investigator demonstrated from abnormal increases in fixed carbon and naphtha insolubility in samples exposed to oven and atmospheric conditions that polymerization and intermolecular reactions caused by heat, and possibly increased also by the action of light, are very largely responsible for such changes, in addition to those accounted for by oxidation and mere loss of volatile matter. It is concluded therefore that the fixed-carbon and material insoluble in naphtha determinations are of value in a comparison of the laboratory residues and residues after exposure of the liquid asphaltic materials used in this investigation.

If there is no material insoluble in naphtha in the volatile matter and none is formed during the progress of the test, the fraction of material insoluble in naphtha should be equal to the percentage in the original material divided by the percentage of residue. If the residue contains more than this calculated or theoretical amount of material insoluble in naphtha it must have been formed during the test. Therefore the actual percentage of naphtha-insoluble matter in the residue divided by the calculated percentage may be called the ratio of increase in material insoluble in naphtha. This ratio multiplied by 100 is called the index of increase and is used to indicate the relative changes which have taken place in the various residues. The relative changes in the fixed carbon content of the various residues may also be determined in the same manner.

In figures 15 and 16 the indexes of increase in naphtha-insoluble material and fixed carbon in the residues, are plotted for each sample and each method of test. When the actual amount of fixed carbon or material insoluble in naphtha is equal to the theoretical or calculated amount, the index of increase, as shown in figures 15 and 16, is 100. It will be noticed that in all cases the increase in naphtha-insoluble material is much greater than the increase in fixed carbon, the index for the residues after 15 weeks' exposure ranging from about 125 to 375 for the material insoluble in naphtha as compared with indexes of 125 to 175 for fixed carbon.

The change in fixed carbon and naphtha-soluble material during the distillation test is slight, the index varying from 100 to 135 for naphtha-insoluble material and from 92 to 117 for fixed carbon. It is probable that there was no actual decrease in fixed carbon, but slight inaccuracies in the test doubtless had a noticeable effect in the distillation residues where the changes were small. The increase in fixed carbon in the volatilization residue is always higher than in the distillation residue, and the same is true for the material insoluble in naphtha except in three cases, but the curves are almost parallel, especially in the case of fixed carbon. In the case of the asphaltic residue the indexes are high when the time of reduction is long, as in the case of samples C and D. In these cases the asphaltic residue has a higher index for fixed carbon than has the residue resulting from a 15-week exposure and the indexes for increase in naphtha-insoluble material approach the values for the residues after 10 weeks' exposure. The indexes are low when the time of reduction is low, as in samples X and Y, where the increase in material insoluble in naphtha is no greater than in the volatilization residue. It is also interesting to note that in general the residues of the high-gravity materials have a lower index for material insoluble in naphtha than have the low-gravity materials. In the case of the index for fixed carbon, however, the high-gravity materials do not fall into any one group.

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[7] B. A. Anderton. Some Relations Between the Characteristics of Steam Distilled Petroleum Residuals. Vol. 20, pt. II, Proc. A.S.T.M. 1920.

It will be seen that the changes in material insoluble in naphtha and in the fixed carbon content are greatest in the residues after 15 weeks' exposure; they are next greatest in residues after 10 weeks' exposure, then in the asphaltic residues, then in the volatilization residues, and least in the distillation residues. The data given clearly demonstrate that all the accelerated evaporation tests now in use for the control of asphaltic materials produce residues which have been less altered by artificial hardening and oxidation than are residues resulting from exposure to the sun and to atmospheric conditions. This corroborates the work of Reeve and Lewis.

FREE CARBON AND CARBENES FORMED ONLY IN HIGH-GRAVITY MATERIALS DURING EXPOSURE

By definition, bitumen is the material soluble in carbon disulphide, asphaltenes are that portion of bitumen insoluble in 86° B. naphtha, and carbenes are that portion of bitumen insoluble in carbon tetrachloride. Referring to tables 3 and 5 it will be seen that the percentage of organic matter insoluble in carbon tetrachloride is exceedingly small in the original materials having low specific gravities; and that there is no great increase in the material insoluble in carbon tetrachloride in their various residues. In these low-gravity materials, therefore, a solubility in carbon tetrachloride is practically the same as a solubility in carbon disulphide; and the material insoluble in 86° B. naphtha may be considered as essentially asphaltenes.

The high-gravity products, however, which originally had from 0.50 percent in the case of sample F to 2.88 percent in the case of sample I of material insoluble in carbon tetrachloride, developed residues which showed substantial increases in material insoluble in carbon tetrachloride. It was indicated clearly, in the case of these high-gravity materials, that solubility in carbon tetrachloride was by no means the same as solubility in carbon disulphide; and it was therefore necessary to test these high-gravity materials and their residues for solubility in carbon disulphide. As shown in tables 3 and 5, these materials have appreciable amounts of material insoluble in carbon disulphide, in their original condition, and in their various residues. In the case of these high-gravity products, therefore, the organic matter insoluble in carbon tetrachloride, as reported in these tables, does not represent carbenes and the organic matter insoluble in 86° B. naphtha does not represent asphaltenes (since they are based on total material rather than total bitumen).

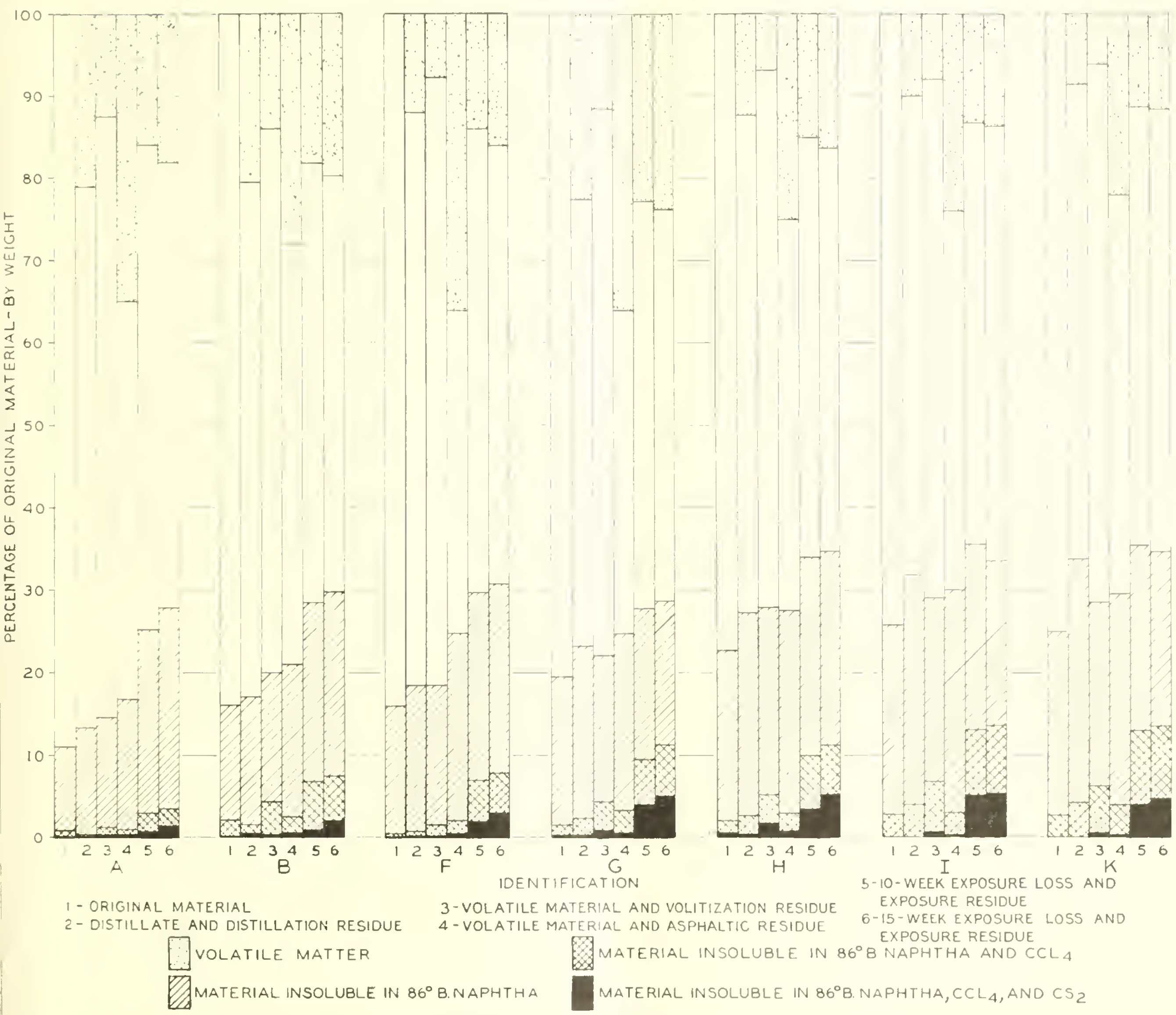
In table 7 the data on solubility have been tabulated to show not only the insoluble matter in the high-gravity materials and their residues but what, by definition, are free carbon (insoluble in carbon disulphide), carbenes, and asphaltenes. The greatest differences between percentage of organic matter insoluble in 86° B. naphtha and percentage of asphaltenes are in the residues after exposure where the free carbon and carbenes have increased to a great extent. In four cases the free carbon and carbenes are greater in the residue from the volatilization test than in the asphaltic residue, the effect of time in the oven test probably being more pronounced than the higher temperature used for a short period in the asphaltic residue test. In two cases the carbenes are less in the distillation residue than in the original material. In figure 17 the volatile matter and the insoluble matter in 86° B. naphtha, carbon tetrachloride, and carbon disulphide are shown for the original materials and their various residues. All percentages are expressed in terms of the weight of the original material.

TABLE 7.—*Comparative solubilities of the high-gravity materials and their residues*

Identification	Solubility test	Original material	Distillation residue	20-gram volatilization residue	Asphaltic residue	10-week exposure residue	15-week exposure residue
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	CS_2 insoluble	0.19	0.24	0.39	0.39	0.87	1.61
	CCl_4 insoluble	.83	.47	1.33	1.46	3.49	4.25
	Naphtha insoluble	10.95	16.89	16.50	25.84	29.95	34.06
	Carbenes	.64	.23	.94	1.07	2.64	3.68
	Asphaltenes	10.78	16.69	16.17	25.55	29.34	32.98
B	CS_2 insoluble	.17	.38	.28	.60	1.06	2.50
	CCl_4 insoluble	2.17	1.83	4.88	3.41	8.27	9.11
	Naphtha insoluble	16.07	21.31	23.26	29.24	34.76	37.16
	Carbenes	2.00	1.45	4.61	2.83	7.29	6.78
	Asphaltenes	15.93	21.01	23.04	28.81	34.06	35.55
F	CS_2 insoluble	.07	.20	.10	.75	2.54	3.69
	CCl_4 insoluble	.50	1.06	1.73	3.12	8.15	9.59
	Naphtha insoluble	16.01	21.08	20.08	38.87	34.62	36.68
	Carbenes	.43	.86	1.63	2.38	5.76	6.13
	Asphaltenes	15.95	20.92	20.00	38.41	32.92	34.25
G	CS_2 insoluble	.19	.29	.95	.71	5.10	6.56
	CCl_4 insoluble	1.58	2.84	4.95	4.98	12.22	14.79
	Naphtha insoluble	19.56	30.00	25.03	38.70	35.65	37.58
	Carbenes	1.39	2.56	4.04	4.30	7.50	8.81
	Asphaltenes	19.41	29.80	24.31	38.26	32.19	33.20
H	CS_2 insoluble	.58	.49	1.84	1.00	4.14	6.41
	CCl_4 insoluble	2.03	3.02	5.68	4.02	11.78	13.40
	Naphtha insoluble	22.74	31.09	29.91	36.81	40.04	41.51
	Carbenes	1.46	2.54	3.91	3.05	7.97	7.47
	Asphaltenes	22.29	30.75	28.60	36.17	37.45	37.50
I	CS_2 insoluble	.08	.08	.69	.24	5.96	6.17
	CCl_4 insoluble	2.88	4.54	7.35	3.84	14.94	15.61
	Naphtha insoluble	25.83	35.21	31.38	39.40	41.08	38.83
	Carbenes	2.80	4.46	6.71	3.61	9.55	10.06
	Asphaltenes	25.77	35.16	30.90	39.25	37.35	34.81
K	CS_2 insoluble	.09	.17	.47	.30	4.51	5.41
	CCl_4 insoluble	2.83	4.71	6.70	5.21	14.66	15.25
	Naphtha insoluble	25.08	37.01	30.48	37.75	40.03	39.12
	Carbenes	2.74	4.55	6.26	4.92	10.63	10.41
	Asphaltenes	25.01	36.90	30.15	37.56	37.20	35.63

Both in figure 17 and table 7 it is apparent that the total material insoluble in naphtha, which in many asphaltic materials may be considered essentially the same as asphaltenes (bitumen insoluble in naphtha), is, in the case of these high-gravity materials and their residues, a combination of free carbon, carbenes, and asphaltenes. The percentage composition of the material insoluble in naphtha, as given in table 8, indicates that free carbon and carbenes are much more pronounced in the residues after exposure than in the residues from the laboratory tests, six of the 15-week residues after exposure having materials insoluble in naphtha which contained about 25 to 40 percent of free carbon and carbenes.

It has been stated by some authorities that free carbon and carbenes are the result of further condensation or polymerization of asphaltenes. Under the conditions of the various laboratory tests and under the weathering conditions of the exposure tests, the 15 low-gravity products did not develop residues with a gain in organic matter insoluble in carbon tetrachloride. The 7 high-gravity products, which had some free



IGURE 17.—Composition of the High-Gravity Materials, Loss in Various Tests and Composition of Their Residues as Determined by Solubility Tests.

arbon as well as an appreciable amount of carbenes, eveloped considerable percentages of these constitu- nts, especially in the residues after exposure. Evi- ently carbonization, which takes place when bitu- ninous materials are subjected to high temperature nd which progresses more rapidly when they are ubjected to sunlight, is intensified when the materials nitially have free carbon and carbenes present together n appreciable amounts. Therefore, specifications call- ng for a high solubility in carbon disulphide and carbon etrachloride should be advantageous in minimizing he possibilities of carbonization playing a part in the eathering of the materials in road service.

UBBARD-FIELD STABILITY TEST USED AS AN INDICATION OF THE RELATIVE BONDING STRENGTH OF FLUID ASPHALTIC MATERIALS WHEN COMBINED WITH A STANDARD AGGREGATE

Slow-curing liquid asphaltic materials are not suitable or surface treatments where exceedingly rapid loss of olatile matter and early hardening are essential to evelop high bonding strength. Whether used in mixed urfaces or in penetrative treatments these products ave, however, some initial bonding strength and develop additional bonding strength depending upon the design of the surface, climatic conditions, and the inherent qualities of the materials themselves.

In order to evaluate adhesiveness or bonding strength tests were made with the Hubbard-Field stability machine,[8] which has been used to demonstrate the effect of consistency and other characteristics of asphalt cements on the stability or resistance to displacement of sheet-asphalt mixtures.

The first phase of this study, the determination of the bonding strength of the original materials, and of their distillation and asphaltic residues, involved the preparation of 3 sets of cylinders for the Hubbard-Field stability test. In each set there were 3 specimens for each material. In 1 set 16.6 percent by volume of the original materials (6.6 to 7.7 percent by weight depending upon their specific gravity) was mixed with 83.4 percent by volume of the standard sand. In the other 2 sets the same percentage by weight of distillation residue and asphaltic residue was used as was used in the cylinders made with the original materials. This gave an almost constant percentage of bitumen by volume in the cylinders containing distillation residue and asphaltic residue. These mixes were tested immediatly for stability at 77° F. and for the purpose of discussion are called series 1 cylinders.

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[8] A study of certain factors affecting the stability of asphalt paving mixtures. Prevost Hubbard and H. C. Field. Proc. A.S.T.M., vol. 26, pt. II, pp. 577-60.

The second phase of the study, the determination of the development of bonding strength, involved the preparation of 6 sets of 3 cylinders each for each material using the same standard aggregate as was used in series 1 and the same percentage of the original materials by volume.

Three sets were placed in a Freas oven regulated at 140° F. and sets were removed at the end of 1, 7, and 14 days. The cylinders were weighed before and after curing and the loss in weight expressed as a percentage of the bituminous material present in the cylinders as made. After weighing, the cylinders were held in an air bath at 77° F. to insure a uniform temperature and then tested at 77° F. for stability.

The other 3 sets were placed in the exposure boxes previously described and subjected to the same exposure conditions as the thin films. Sets were removed at the end of 5, 10, and 15 weeks and tested in the same manner as the oven-cured cylinders. For comparative purposes 2 additional sets of cylinders were made using as a binder the amounts of distillation residue and asphaltic residue which would have been obtained if the bitumen in the cylinders made with the original materials had been subjected to the distillation or asphaltic residue test. These two sets were tested immediately. For the purpose of discussion these are called series 2 cylinders. Table 9 gives the percentage composition of each mix by weight and by volume.

The aggregate was a Potomac River sand which had been separated on standard sieves and recombined for each mix to obtain the following grading:

Passing sieve no.—	Retained on sieve no.—	*Percent*
10	20	3.9
20	30	6.4
30	40	10.3
40	50	14.2
50	80	30.9
80	100	16.8
100	200	16.7
200		0.8

This sand had a specific gravity of 2.653 and the voids, as determined by the Bureau of Public Roads void determinator,[9] were 34.5 percent. It conforms essentially to Richardson's grading for heavy-traffic sheet asphalt sand without the filler (the material passing the no. 200 sieve), which was omitted not only to provide an open mix for possible loss of volatile matter, but also to eliminate the effect of filler on the bonding strength of the mixtures.

The asphaltic materials and sand were thoroughly mixed by hand. Mixtures containing the original asphaltic materials were mixed at room temperature. Mixtures containing the distillation residues were warmed to 100° F. and those containing the asphaltic residues were heated to 200° F. to expedite mixing and to insure uniform coating. The cylinders were compacted under a load of 3,000 pounds per square inch. The method of compaction recommended by Hubbard and Field was varied in the following particulars:

1. Cylinders containing the original materials and distillation residues were compressed at room temperature.

TABLE 8.—*Composition of the total material insoluble in naphtha of the high-gravity materials and their residues*

Identification	Naphtha-insoluble matter composed of—	Original material	Distillation residue	20-gram volatilization residue	Asphaltic residue	10-week exposure residue	15-week exposure residue
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	Free carbon	1.7	1.4	2.4	1.5	2.9	4.7
	Carbenes	5.8	1.4	5.7	4.1	8.7	7.8
	Asphaltenes minus carbenes	92.5	97.2	91.9	94.4	88.4	87.5
B	Free carbon	1.1	1.8	1.2	2.1	3.1	6.7
	Carbenes	12.5	6.8	19.8	9.6	20.8	17.8
	Asphaltenes minus carbenes	86.4	91.4	79.0	88.3	76.1	75.5
F	Free carbon	.4	.9	.5	1.9	7.3	10.1
	Carbenes	2.7	4.1	8.2	6.1	16.2	16.6
	Asphaltenes minus carbenes	96.9	95.0	91.3	92.0	76.5	73.3
G	Free carbon	1.0	1.0	3.8	1.8	14.3	17.5
	Carbenes	7.1	8.5	16.0	11.0	20.0	21.9
	Asphaltenes minus carbenes	91.9	90.5	80.2	87.2	65.7	60.6
H	Free carbon	2.5	1.6	6.2	2.7	10.4	15.4
	Carbenes	6.4	8.1	12.9	8.2	19.1	16.9
	Asphaltenes minus carbenes	91.1	90.3	80.9	89.1	70.5	67.7
I	Free carbon	.3	.2	2.2	.6	14.5	15.9
	Carbenes	10.9	12.7	21.2	9.2	21.9	24.3
	Asphaltenes minus carbenes	88.8	87.1	76.6	90.2	63.6	59.8
K	Free carbon	.4	.5	1.7	.8	11.3	13.8
	Carbenes	10.9	12.3	22.5	13.0	25.4	25.2
	Asphaltenes minus carbenes	88.7	87.2	75.8	86.2	63.3	61.0

TABLE 9.—*Composition of cylinders for Hubbard-Field stability test*

Identification	Specific gravity of asphaltic material at 77° F.	Percentage of bitumen by weight in all series 1 cylinders and those of series 2 made with original material	Percentage of bitumen by volume in series 1 distillation residue cylinders	Percentage of bitumen by volume in asphaltic residue cylinders of series 1	Series 2—distillation residue cylinders			Series 2—asphaltic residue cylinders		
					Residue, percentage of original material	Percentage of bitumen by weight	Percentage of bitumen by volume	Residue, percentage of original material	Percentage of bitumen by weight	Percentage of bitumen by volume
A	1.001	7.0	16.1	15.9	78.9	5.6	13.1	65.0	4.7	11.0
B	1.013	7.1	16.0	15.8	79.4	5.8	13.3	71.9	5.2	11.9
C	0.942	6.6	15.9	15.7	74.0	5.0	12.3	66.5	4.5	11.0
D	0.955	6.7	16.1	15.9	82.3	5.6	13.7	75.1	5.1	12.4
E	0.976	6.8	16.2	15.9	90.9	6.3	15.3	66.5	4.7	11.3
F	1.066	7.4	16.3	15.9	88.0	6.6	14.7	64.0	4.9	10.9
G	1.079	7.5	16.1	15.9	77.5	5.9	13.0	63.9	4.9	10.7
H	1.101	7.7	16.4	16.2	87.7	6.8	14.7	75.1	5.9	12.7
I	1.082	7.5	16.4	16.0	90.1	6.8	15.0	75.9	5.8	12.6
K	1.088	7.6	16.5	16.2	91.5	7.0	15.3	78.1	6.0	13.1
L	0.972	6.8	16.3	16.0	84.4	5.8	14.1	65.1	4.6	11.2
M	0.967	6.8	16.2	16.0	79.9	5.5	13.4	65.3	4.5	11.2
N	0.981	6.9	16.5	16.2	89.5	6.2	15.0	70.2	4.9	11.9
O	0.972	6.8	16.4	16.0	88.4	6.1	14.9	65.2	4.6	11.2
P	0.967	6.8	16.2	16.0	78.6	5.4	13.2	67.9	4.7	11.4
R	0.979	6.9	16.6	16.2	90.6	6.3	15.3	71.2	5.0	12.1
S	0.952	6.7	16.3	15.7	83.9	5.7	14.1	64.8	4.4	10.7
T	0.960	6.7	16.1	15.9	86.1	5.9	14.5	68.9	4.7	11.5
V	0.966	6.8	16.4	16.1	88.2	6.0	14.7	71.7	5.0	12.2
X	0.951	6.7	16.0	15.8	72.3	4.9	12.0	65.6	4.5	11.0
Y	0.963	6.8	16.1	15.9	76.8	5.3	12.8	71.1	4.9	11.8
Z	0.972	6.8	16.0	16.2	83.2	5.7	13.8	76.4	5.3	12.7

2. Cylinders containing asphaltic residues were compressed at a temperature of 200° F.

3. Cylinders were formed without tamping.

4. In forming cylinders containing orginal material, pressure was released as soon as the pressure required was reached. With cylinders containing distillation residues and asphaltic residues pressure was maintained for 1 and 2 minutes respectively. In forming cylinders containing asphaltic residues the mold was flooded with water to cool to room temperature as soon as maximum pressure was reached.

Determinations made on the compacted specimens showed the cylinders containing original material to have an average of 34.3 percent voids in the mineral aggregate and 21.9 percent voids in the mix. The average percentage of voids in the mineral aggregate

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[9] Researches on Bituminous Paving Mixtures, PUBLIC ROADS, vol. 7, no. 10, December 1926.

TABLE 10.—*Characteristics and stability of cylinders of series 1*

Identification	Original material			Distillation residue		Asphaltic residue	
	Stability at 77° F.	Float at 77° F.	Furol viscosity at 122° F.	Stability at 77° F.	Float at 122° F.	Stability at 77° F	Penetration at 77° F.
A	175	9	94	1, 100	57	4, 125	87
B	275	20	205	1, 625	110	4, 775	81
C	100	2	68	775	59	3, 400	95
D	200	9	199	750	60	3, 100	88
E	200	36	294	400	31	3, 650	104
F	200	20	94	375	34	5, 250	101
G	150	8	68	875	62	5, 875	82
H	300	65	297	1, 000	75	5, 525	92
I	325	75	320	800	57	5, 075	92
K	475	100	478	825	73	5, 250	100
L	275	24	274	750	51	4, 375	93
M	200	7	151	675	66	4, 150	112
N	350	48	677	800	62	3, 750	105
O	225	25	300	375	30	4, 025	101
P	175	12	201	900	82	4, 000	107
R	375	17	735	750	50	4, 375	102
S	150	35	178	525	46	3, 375	106
T	225	46	300	475	50	3, 500	102
V	225	52	458	775	59	3, 575	99
X	125	8	111	1, 050	101	3, 950	104
Y	175	21	281	1, 300	122	4, 000	85
Z	300	53	613	1, 575	123	4, 400	86

was 33.5 percent for the cylinders containing distillation residues and 32.9 percent for those containing asphaltic residues.

The results of the stability tests on cylinders in series 1 are given in table 10 and of those on series 2 are given in table 11. All results are the average of three cylinders.

STABILITY OR BONDING STRENGTH DEPENDS NOT ONLY ON THE CONSISTENCY BUT ALSO ON THE INHERENT PROPERTIES OF THE ASPHALTIC BINDER

The results given in table 10 are shown graphically in figure 18. The stability at 77° F. of the cylinders made with the original materials is plotted against the Furol viscosity at 122° F. and the float test at 77° F. The stability of the cylinders containing distillation residue is plotted against results of float tests at 122° F. on the distillation residues. In the case of the cylinders containing asphaltic residues, since the consistencies of the bitumen are all approximately the same, the stability values are plotted for each sample independently.

Examination of these figures shows that the stabilities developed by the sand mixes in which the original material and distillation residues were used as binders are roughly proportional to the consistency of the contained bitumen and that, for the same viscosity, (Furol at 122° F.) the high-gravity materials give higher stability than the low-gravity materials. In general the asphaltic residues of the high-gravity materials yield the higher stabilities. In the graph showing the stability of the original material plotted against the time of float at 77° F. it is seen that for the same time of float the high-gravity materials do not give the higher stabilities. Since these high-gravity materials have higher float-test values at 77° F. for a given viscosity at 122° F. than the low-gravity materials, the time of float determined at the temperature at which the stability test is made may be a better index of the bonding strength than the Furol viscosity test run at a higher temperature.

Examination of the figure shows that the stabilities and consequently the workability of mixtures made with samples I and R are about the same but there is a difference of over 400 seconds in their Furol viscosities at 122° F. Samples K and V have about the same viscosity at 122° F. but, as measured by the float test at 77° F., sample K is twice as viscous as sample V. The mixture made with sample K has much the greater stability and it would be more difficult to process on the road.

In order to eliminate materials which are difficult to process at normal temperatures, some States have found it necessary to include in their specifications a maximum float-test value at 77° F. on the original material as well as a Furol viscosity at 122° or 140° F. There is no doubt that materials of the same consistency as measured by the viscosity at 122° F. and by the penetration at 77° F. of the asphaltic residues, have different binding values and that the seven high-gravity materials included in this study have the greater bonding strength for equivalent consistencies as measured by viscosity or penetration of the asphaltic residue.

While the variations in stabilities produced by the original materials may be due largely to variations in

TABLE 11. *Characteristics and stability of cylinders of series 2*

Identification	Stability at 77° F. of original material	Oven exposed cylinders						Atmospheric exposed cylinders						Distillation residue cylinders		Asphaltic residue cylinders	
		Stability at 77° F. after exposure for—			Percentage loss of bitumen in—			Stability at 77° F. after—			Percentage loss of bitumen in—			Stability at 77° F.	Theoretical loss of bitumen	Stability at 77° F.	Theoretical loss of bitumen
		1 day	7 days	14 days	1 day	7 days	14 days	5 weeks	10 weeks	15 weeks	5 weeks	10 weeks	15 weeks				
															Percent		*Percent*
A	175	300	350	475	6	12	16	700	1, 150	1, 225	13	18	20	1, 125	21	3, 525	35
B	275	475	750	1, 000	6	13	17	1, 100	1, 575	1, 550	15	18	21	1, 475	21	4, 050	28
C	100	175	400	550	11	23	27	600	925	1, 300	25	27	28	675	26	2, 950	34
D	200	325	375	650	7	12	16	800	1, 125	1, 650	18	19	21	750	18	2, 925	25
E	200	200	225	325	2	3	6	325	700	1, 050	6	9	11	400	9	3, 075	34
F	200	225	200	425	2	4	8	650	1, 475	2, 775	9	13	17	375	12	4, 575	36
G	150	175	275	475	3	8	13	675	1, 875	3, 400	14	19	23	850	23	4, 975	36
H	300	425	575	975	1	4	7	1, 125	2, 775	4, 675	8	12	16	925	12	4, 650	25
I	325	450	675	1, 125	2	4	7	1, 375	3, 175	4, 050	8	10	14	800	10	4, 900	24
K	475	625	825	1, 250	3	3	5	1, 375	3, 325	4, 250	5	9	12	875	9	5, 625	22
L	275	325	525	575	4	8	10	675	1, 150	1, 500	10	13	16	750	16	3, 775	35
M	200	275	500	700	6	11	14	825	1, 475	2, 075	15	18	20	700	20	3, 650	35
N	350	425	700	1, 000	4	7	10	950	1, 575	2, 125	8	10	11	750	11	3, 525	30
O	225	250	400	500	3	5	10	700	1, 025	1, 400	8	11	12	375	12	3, 475	35
P	175	300	700	925	6	12	17	1, 000	1, 950	2, 550	17	20	21	925	21	3, 550	32
R	375	450	650	975	4	5	9	875	1, 725	2, 150	6	8	10	625	9	3, 825	29
S	150	175	325	525	4	8	13	700	1, 375	1, 850	11	15	16	475	16	2, 950	35
T	225	275	450	625	4	7	11	775	1, 525	1, 975	9	12	13	500	14	3, 325	31
V	225	300	475	775	3	6	9	875	1, 675	2, 050	6	10	11	700	12	3, 550	28
X	125	225	425	675	7	14	20	850	1, 875	2, 300	19	24	26	1, 025	28	3, 700	34
Y	175	300	500	750	6	9	15	1, 100	2, 250	2, 700	15	19	20	1, 225	23	3, 800	29
Z	300	475	775	1, 000	5	8	11	1, 350	2, 575	2, 700	10	14	15	1, 425	17	4, 300	24

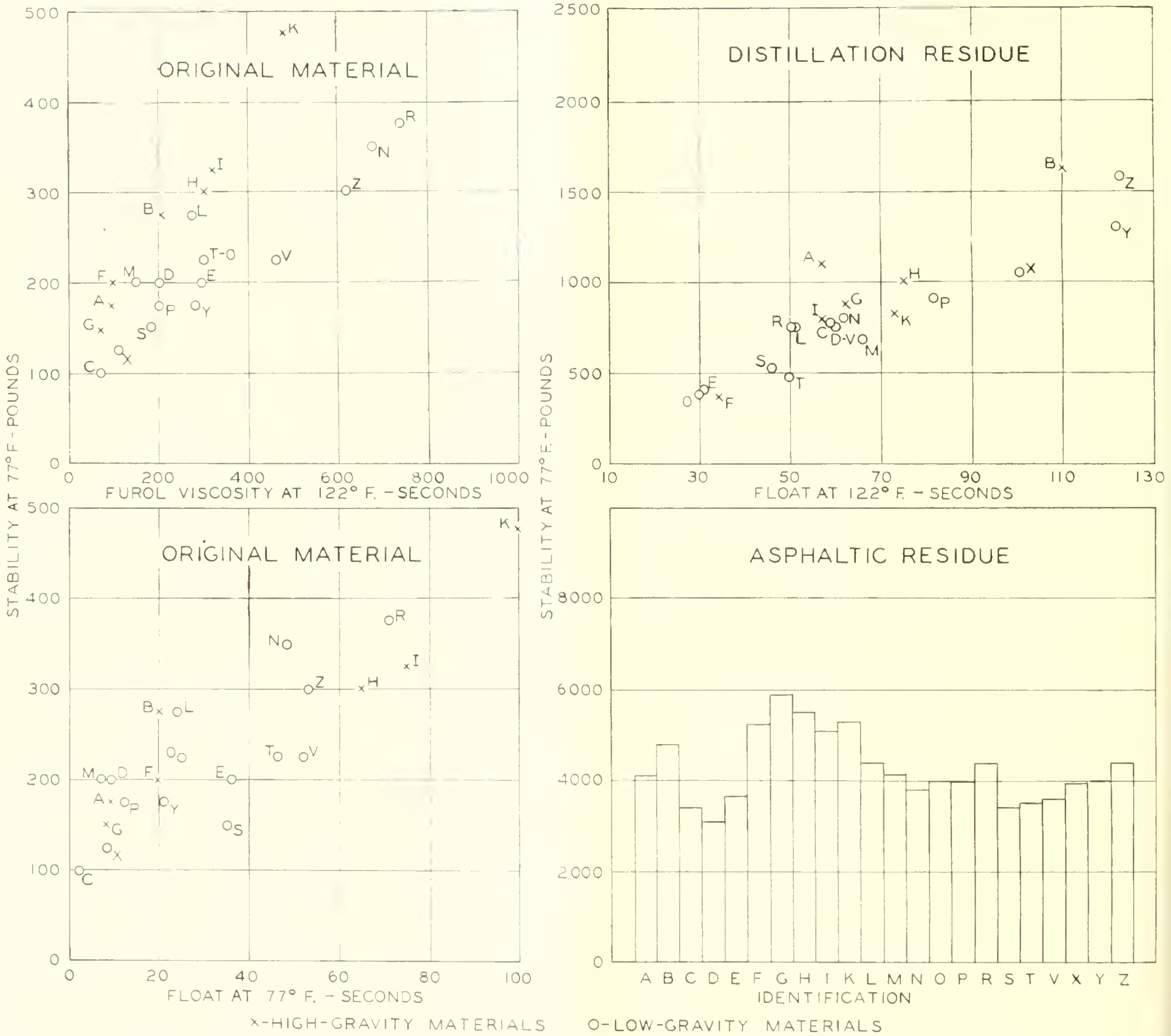

Figure 18.—Relation Between the Consistencies of Original Materials, Distillation Residues, and Asphaltic Residues and the Stability at 77° F. of Cylinders of Series 1.

consistencies, the wide differences in stability produced by asphaltic residues having relatively small differences in penetration seem to indicate that factors other than consistency influence the bonding strength of these semisolid residues.

In figure 19 the loss of bitumen in the cylinders exposed in cases for 5 weeks is plotted against the loss of bitumen in the cylinders cured in an oven for 2 weeks. The stability of the exposed cylinders is plotted against the stability of the oven cylinders. Although the loss of bitumen is about the same for both methods the stability of the cylinders exposed for 5 weeks is, in all cases except 2 (samples N and R), greater than the stability of the oven-cured cylinders. Just as changes not entirely due to loss of volatile matter produced hardening and inherent changes in the exposed films, so here greater bonding strength or stability is developed in the exposed cylinders although the loss of volatile matter is practically the same under both conditions of treatment.

In figure 20 the data for the cylinders of series 2 containing distillation residues and cylinders exposed for 5 weeks are plotted in the same manner. Although in all cases the distillation-residue cylinders represent a greater percentage of loss of bitumen than the actual loss occurring in 5 weeks of exposure, the stabilities of the exposed cylinders are greater than the stabilities of the distillation-residue cylinders except in 9 cases and, of those 9 cases, 7 of the materials lost at least 6 percent more in the distillation test than did the cylinders exposed for 5 weeks.

Similar comparisons may be made for cylinders exposed for 15 weeks and cylinders containing distillation and asphaltic residues. However, comparisons are made in a different manner in figure 21 where the stability and the percentage of loss of bitumen of the exposed cylinders and the theoretical loss of the cylinders containing residues are plotted for each sample. It is seen that the stabilities of cylinders exposed for 15 weeks are much greater than the stabilities of the cylin-

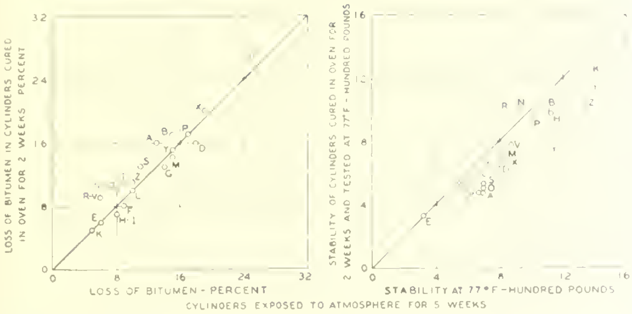

Figure 19.—Comparison of Losses and Stability of Cylinders Subjected to Oven Curing for 2 Weeks with Those of Cylinders Exposed to Atmosphere for 5 Weeks.

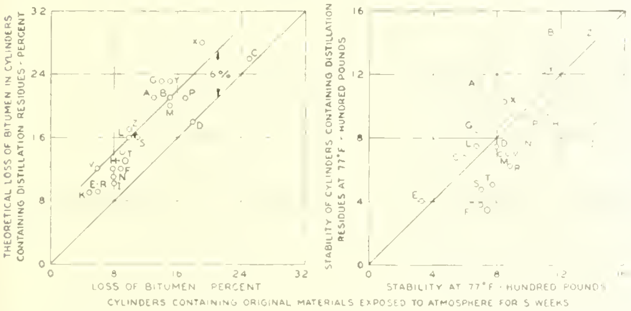

Figure 20.—Comparison of Losses and Stability of Cylinders Exposed to Atmosphere for 5 Weeks with Those of Cylinders Containing Distillation Residues of Series 2.

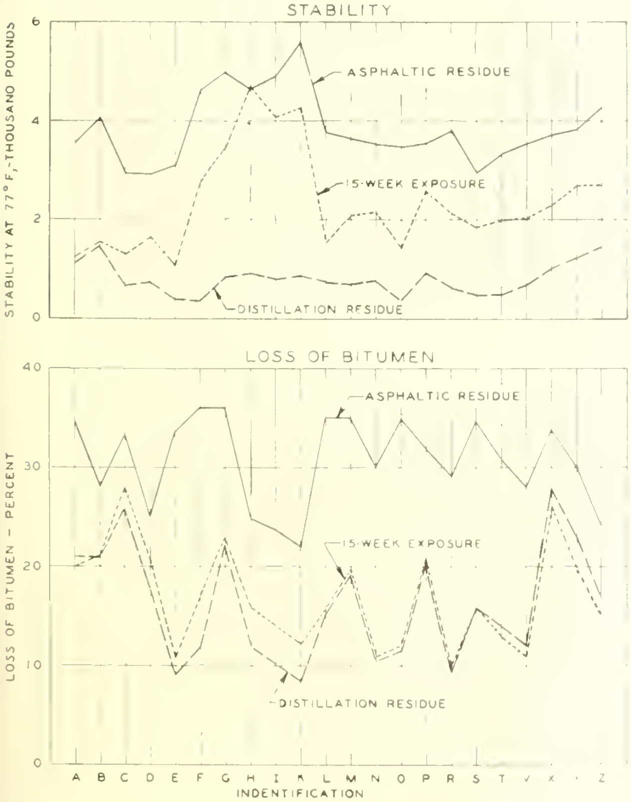

Figure 21.—Comparison of Loss of Bitumen and Stability of Cylinders Exposed to Atmosphere for 15 Weeks and Cylinders Containing Distillation and Asphaltic Residues of Series 2.

ders containing distillation residues except in the case of samples A and B. These are 2 of the 3 samples which were altered to the greatest extent in the thin film exposures. The loss in the samples exposed for 15 weeks is about equal to the loss in the distillation test, being a little higher for samples F, H, I, and K but not enough to account for the much higher stabilities obtained in the cylinders of these materials exposed for 15 weeks. The stabilities of the cylinders exposed for 15 weeks do not reach the stabilities of the corresponding cylinders containing asphaltic residues except in the case of sample H, which was one of the materials having the highest gravity, and neither does the loss of bitumen in the cylinders exposed for 15 weeks approach the loss in the asphaltic residue test.

It has been held by some that a certain amount of material insoluble in naphtha is essential if an asphaltic material has or is to develop bonding strength. It is of interest to note that the high-gravity materials which have the greatest amount of material insoluble in naphtha, originally have higher stabilities than the low-gravity materials of the same viscosity at 122° F. and, with the exception of samples A and B, develop the highest stabilities after 15 weeks exposure.

In connection with these comparisons of stability, it should be remembered that the cylinders made with residues contained material of uniform consistency distributed evenly throughout the entire mass. When the cylinders were exposed to atmospheric and oven volatilization the evaporation of the volatile matter undoubtedly was greatest at the surface of the specimens and the cylinders after various intervals of exposure no doubt had a bituminous binder of variable consistency. Differences in consistency of bituminous material throughout the mass of the exposed cylinders may be considerable during the early stages of the exposure. Figure 22 shows the percentage of loss in thin films of bitumen compared with the loss in cyl-

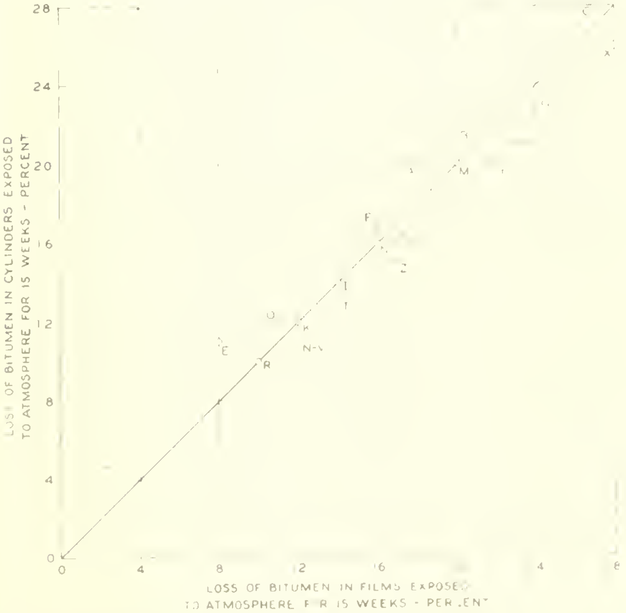

Figure 22.—Loss in Thin Films of Bitumen Exposed for 15 Weeks Compared with Loss of Bitumen in Cylinders Exposed for Same Time.

inders exposed for 15 weeks. There is a remarkable agreement between the volatility of the various bituminous materials under widely different conditions. It is therefore concluded that the development of increased stability or bonding strength in the exposed cylinders is caused by the same conditions which are responsible for the greater hardening and changes in the inherent structure of the bituminous materials when exposed in the thin films to atmospheric conditions.

SUMMARY OF CONCLUSIONS

It is realized that the exposure of thin films of the original materials and the exposure of the materials admixed with a mineral aggregate in the form of cylinders are not comparable to service conditions; but bituminous surfaces containing materials similar to these indicate the beginning of deterioration by incipient surface failures. The effects of weathering on the original materials and mixtures of original materials with mineral aggregate should prove of value in anticipating service behavior. The tendency of road surfaces to ravel and dust, the necessity for the use of additional oil in reprocessing, and the frequency of retreatments or reprocessing required are all related to the weather resisting properties of the bituminous binder.

This investigation was undertaken to determine the adequancy of present laboratory tests in determining the weathering characteristics of slow-curing liquid asphaltic road materials. The work is being continued with materials from other sources and processes and, while at this time no particular laboratory tests or combinations of tests are recommended, the following conclusions based on the data developed seem justified:

1. The high-gravity materials and their residues which were studied are more susceptible to temperature changes than the low-gravity materials and their residues with the exception of the materials A and B.

2. For materials from the same source the amount of asphaltic residue generally increases with increase in Furol viscosity and generally decreases with increases in distillation and volatilization loss. Certain exceptions to this relation have been noted.

3. The asphaltic-residue test, when used alone, does not indicate the probable rate of loss of volatile matter in the material under exposure even though the time of reduction to the specified penetration is considered.

4. The distillation test more nearly indicates the ultimate loss which occurs in thin films and mixed samples exposed to the sun and air. The relative rates of volatilization of the various materials investigated can more readily be anticipated from the distillation curves than from the oven volatilization test or the asphaltic residue test alone.

5. There is more artificial hardening due to causes other than loss of volatile matter, in samples exposed to atmospheric conditions than in samples submitted to the various laboratory heat tests.

6. The development of a ductile residue in the asphaltic residue test does not indicate that the material will develop a ductile residue when exposed to the sun.

7. Changes in inherent characteristics, which may be attributed to chemical action, namely, oxidation, polymerization and carbonization, take place to the greatest extent under exposure to the sun and least during distillation.

8. Carbonization does not occur during laboratory heat tests or outdoor exposure, as made in this study, in those materials which originally have little or no matter insoluble in carbon tetrachloride. It does occur in materials which initially have some material insoluble in carbon disulphide and appreciable amounts insoluble in carbon tetrachloride. Specifications calling for high solubility in carbon disulphide and carbon tetrachloride will be advantageous in minimizing the possibilities of carbonization playing a part in the weathering of the materials in road service.

9. The bonding strengths of the original materials are roughly proportional to their consistencies.

10. Asphaltic residues of approximately the same penetration, when admixed with a standard sand, do not always have the same bonding strength or stability.

11. None of the laboratory tests now used to indicate probable service behavior produce residues which either alone or in mixtures are as much altered as are those developed under the exposure as made in this investigation.

12. The bonding strength or stability of mineral aggregate mixed with liquid asphaltic materials of the kind studied depends upon characteristics which cannot be ascertained under the present method of testing.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF MAY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
	$	$	$	$		$	$	$			$		$
Alabama	4,185.067.00	203.693.42	112.751.38	90.942.04	7.9	5.548.233.17	3.093.622.76	2.454.610.41	50.8	303.5	505.455.36	45.4	473.237.50
Arizona	3.804.731.00	1.214.243.96	1.197.137.74		80.5	3.037.851.77	2.440,593.37		47.9	195.7	135.687.83	8.0	31.312.06
Arkansas	3.374.167.00	220.374.92	145,296.08	75.078.84	8.9	2,598.906.11	2,181.952.94	416.953.17	53.4	120.6	582,501.90	32.7	464.416.08
California	7,803.677.00	2.393.798.95	1.915,551.02		79.8	7.450.976.73	5.638.116.54		38.6	214.7	211.793.40	11.6	38.216.04
Colorado	3.437.265.00	1.422.654.47	1.412.074.12		92.8	1.816.680.27	1.816,680.27		37.7	51.7	186.600.00	6.5	21.910.61
Connecticut	1.404.213.00					1,575.560.82	1.399.781.88	175.778.94	21.5	30.8			4.431.12
Delaware	909.544.00	195.432.80	195.432.80		2.7	698.741.30	698.741.30		44.6	14.7	5.770.00	.3	9.599.90
Florida	2.615.917.00	761.355.47	515.381.11	245.974.36	28.2	2.459.751.14	1.902.446.21	556.694.53	63.4	87.8	21,281.75	.1	176.807.93
Georgia	5.045.592.00	783.061.84	783.061.84		43.3	2.484.947.12	2.484.947.12		50.0	168.3	836.748.36	55.5	940.534.68
Idaho	2.166.858.00	680.567.73	665.743.06		73.9	1.395.566.16	1.360.848.98		37.9	101.3	22,580.24	.1	117.685.72
Illinois	4.585.971.00	50.872.54	50.872.54		1.0	2,480.573.79	2.480,573.79		27.4	43.7	1.679.199.05	14.4	375.325.62
Indiana	4.717.786.00					3.615.626.78	3.610.284.38		30.1	103.7	1.107.501.62	22.9	
Iowa	5.027.830.00	908.204.18	897.000.00		63.7	4.275.829.22	3.970,780.00		57.6	196.4	128.675.50	9.0	31.374.50
Kansas	5.044.802.00	1.146.186.50	1,146.177.90		177.4	4.107.694.34	3.571.811.83		62.7	220.1	26.234.83	.3	577.44
Kentucky	3.608.332.00	191.016.22	186.559.93		14.5	2.856.956.54	2,548.949.75		47.4	215.1	545.273.65	24.4	27.548.67
Louisiana	2.914,295.00	68.560.34	68.560.34		2.4	2.590.876.68	2.384.225.68		35.3	68.2	236.575.70	7.7	224.933.28
Maine	1.617.560.00					1.471,513.41	1.435.951.46		39.8	43.4	65.268.34	.9	116.340.20
Maryland	1.782.263.00					801.143.78	791.495.03		33.1	14.5	316.571.75	6.4	673.896.22
Massachusetts	1.101.716.00	161.148.54	83,952.64	69,984.24	4.2	1,248.813.06	933.153.42	315.659.64	50.6	33.6	2.982.00		81.627.94
Michigan	6.113.389.00	63.000.00	63.000.00		1.7	4.576.680.00	4.527.680.00	49.000.00	30.6	220.9	1.003.716.00	43.8	518,993.00
Minnesota	4.561.011.00	2.156,273.55	2.156.273.85		448.8	1.757.802.84	1.709.819.97	47.982.57	25.6	240.0	694.917.18	71.1	
Mississippi	3.489.337.00	288.524.53	164.210.19	124.314.34	12.8	4.246.750.55	2.294.222.03	1.913.896.58	38.5	222.2	288,105.12	28.1	742.799.66
Missouri	5.237.532.00	895.421.61	695.097.86		43.5	4.274.290.56	3.934.147.99	68.548.60	59.6	145.1	284.427.21	12.0	323.858.94
Montana	4.463.849.00	871.637.87	871.621.87		79.7	3.904.149.79	3.491,348.36	332.801.43	49.2	272.1	99.722.97	48.3	1.155.80
Nebraska	3.914.481.00	1,530.754.98	1.164.748.12	108.538.00	189.2	3.553.681.35	2.713.138.69		47.1	163.7	35.294.58	8.9	1.299.61
Nevada	2.909.387.00	907.938.29	907.938.29		137.7	1.790.081.44	1.790.081.44		31.3	115.6	131.524.90	6.8	79.842.37
New Hampshire	725.739.00					652.808.61	646.301.20		58.2	10.5			79.437.50
New Jersey	3.099.370.48	12.635.23	12,635.23		.2	2.772.056.71	2.617.135.70	139.466.42	20.9	40.6	104.547.21	2.3	365.052.34
New Mexico	2.896.467.00	1,504.324.71	1.504.324.71		187.4	1.407.888.72	1.392.142.29		34.8	91.6			
New York	10.271.846.00	329.617.14	229.557.14	43.000.00	7.5	11.271.564.18	9.827.929.18	315.000.00	32.5	230.3	150.197.50	8.6	64.161.58
North Carolina	4.761.147.00	809.366.26	513.889.90	295.476.36	70.6	2.912.350.38	2.596.125.93	310.131.36	41.0	416.4	1.010.197.07	131.8	640.934.10
North Dakota	2.902.224.00	870.227.69	870,224.18		404.0	1,336.683.70	1.245.667.99	141.015.71	27.6	361.9	699.765.76	208.0	86.566.07
Ohio	7.277.758.00	738.815.47	737.221.63		18.9	6.748.768.00	6.431.395.00	51.410.00	49.6	168.0	77.578.00	5.0	31,263.37
Oklahoma	4.608.399.00	661.230.78	659,753.26		61.2	3.505.422.39	3.505.422.39		50.6	229.0	48.846.79	7.6	394.376.56
Oregon	3.053.448.00	865.630.84	753.419.84		58.9	2.281.769.35	2.122.823.15	58.505.67	39.9	123.2	171.458.33	1.4	5.746.68
Pennsylvania	6.691.194.00	61,933.02	61,933.02		1.2	5.966.094.31	5.918.696.55		27.7	123.4	567.597.53	7.3	142.966.60
Rhode Island	999.354.00	18.144.13	18.144.13		.5	979.621.58	979.621.58		47.7	20.0			1.585.29
South Carolina	2.729.583.00	186.114.32	186.114.32		21.3	2.004.824.57	2.002.094.95	2.729.62	44.8	184.5	264.322.12	14.8	277.051.61
South Dakota	3.005.739.00	909.016.45	889.675.06	19.341.39	140.8	1.902.810.82	1.627.626.66	275.184.16	25.1	277.7	214.856.94	48.2	273.580.34
Tennessee	4.240.309.00	542.324.38	428.187.66	114,136.72	23.0	3.769.188.16	3.307.307.50	461.880.66	51.2	142.5	399.951.25	24.2	110.832.59
Texas	12.122.012.00	3.182.653.30	2.592,062.09		469.1	7.971.503.44	7.350.365.67		35.2	501.0	785.576.78	61.7	1,394.007.46
Utah	2.374.205.00	1.077.150.76	1.074.382.05		112.5	1.153.093.57	1.153.093.57		46.6	82.3	68.204.10	.4	73.525.28
Vermont	928,184.00	90.524.22	89.926.93		7.4	818,166.22	790,012.97		36.3	36.4	32.234.71	1.0	16.009.39
Virginia	3.708.379.00	561.488.30	543.915.32	17.572.98	20.4	2.662.658.52	2.547.519.10	111.852.63	41.4	101.5	431.836.98	23.5	185.107.60
Washington	3.057.934.00	751.986.13	750.555.05		42.4	2.236.630.53	2.230.389.24	3.356.82	31.4	63.2	68.527.19	1.4	8.462.52
West Virginia	2.013.405.00	194.881.82	194.881.82		6.4	1.706.791.18	1.700.791.18		58.4	64.7	49.466.14	1.2	68.265.86
Wisconsin	4.862.441.00	336.949.10	326.646.27	1.190.00	16.3	3.532.524.10	3.658.844.19	21,500.00	38.4	183.5	484.454.42	25.9	392.496.16
Wyoming	2.250.663.00	916.568.30	798.573.00	80.400.00	163.8	1.516.017.71	1.399.059.40	55.800.00	28.3	287.0	40.411.52	10.0	12.619.08
District of Columbia													
Hawaii	1.683.956.00	123.221.48	110.214.35	12.994.32	6.3	1.626.253.71	1.325.047.89	251.205.82	23.1	26.5	25.590.00	1.2	223.103.76
TOTALS	186.106.328.48	31.559.526.90	28.744.679.64	1.298.943.59	3.434.7	148.005.174.15	132.180.808.43	8.530.965.34	41.1	7.374.0	14.850.660.18	1.050.7	10.330.180.23

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF MAY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 2.092.533	$ 94.891.56	$ 94.891.56		1.5	$ 1.030.554.58	$ 1.030.554.58		17.9	29.4	$ 788.406.39	24.5	$ 178,680.47
Arizona	781.794	123.633.23	122.192.35		3.6	236.990.31	236.990.31		32.1	5.1	259.459.07	3.0	163.152.27
Arkansas	1.687.084	169.853.84	157.838.84	$ 12,015.00	4.4	775.339.15	706.371.87	$ 68.967.28	50.7	22.9	822.873.29	13.4	
California	4.213.986	1.177,423.37	1.058,836.93		13.1	2.225.768.20	1,992.801.76		11.1	29.2	702.424.59	7.7	459.922.72
Colorado	1,718.633	616.409.92	570.602.27		12.0	732.163.15	732.163.15		21.9	14.5	332.431.87	7.7	83.435.71
Connecticut	802.407	48.325.68	48.325.68		.5	687.857.65	684.715.77	3.141.88	50.2	9.2	68,293.81	.5	1.071.74
Delaware	454.772	75.309.50	75.309.50		.8	203.298.40	203.298.40		21.7	1.9	139.750.00	4.9	36,414.10
Florida	1.307,959	133.057.48	73.305.33	59.752.15	2.5	1,412.666.73	1.234,653.67	178.013.06	42.1	14.9			
Georgia	2,724.620	197.564.30	197.564.30		9.0	1.026.553.10	1,026.553.10		30.0	33.1	289,147.47	14.4	1.211.355.13
Idaho	1.197.829	161,758.22	158,915.77		3.6	712.157.31	707.404.20		10.6	11.0	258.753.89	3.7	72.755.14
Illinois	7.718.839	71,487.70	71,487.70		.9	6.409.983.76	6.409,983.76		32.2	66.8	550.966.80	2.7	686.400.74
Indiana	4,818.165	42.730.27	42,730.27		.8	2.240,428.03	2,240,428.03		4.6	39.9	1.374.338.10	29.7	1.160,668.60
Iowa	2.815.585	299.766.26	295.050.00		12.0	1,520.528.32	1.428,595.00		52.4	27.9	408,074.50	10.0	683.865.50
Kansas	2.522,401	293.818.26	293.818.26		9.9	2.336.685.05	2.188.392.84		64.1	26.9	40,189.90	.4	
Kentucky	2.029.687	66,049.66	66,049.66		2.3	683.692.80	683,515.91		24.9	15.8	423,277.66	9.5	856,543.77
Louisiana	1.457.148	159.911.74	159.911.74		2.5	775.672.26	775.672.26		28.0	21.7	521.564.00	2.9	
Maine	909.878	89.479.37	88.353.80		1.6	679.118.79	677.747.49		33.8	14.4	62.967.38	.7	80.509.33
Maryland	891,132					250,248.26	246.098.26		11.8	2.1	159.044.85	1.5	485.988.89
Massachusetts	5.007.199	53,896.49	30,896.49	23.000.00	1.5	3.946.565.68	3,932.465.68	14.100.00	28.2	12.6	799,041.34	2.4	244,795.49
Michigan	3.438.781	180,700.00	180,700.00		2.2	2.553.720.00	2.551.570.00		21.6	34.1	239,275.00	2.1	467,236.00
Minnesota	3.719.143	660,594.74	660,501.33		42.5	1,358.218.00	1,355.718.00	2.500.00	28.1	40.9	1,086.183.87	16.8	616.739.80
Mississippi	1,744,669	122,848.45	110.388.95	12.459.50	3.8	425.983.90	425.983.90		21.1	19.2	425.061.11	9.6	783.235.04
Missouri	4.019.501	372,259.49	352.033.11		8.3	1,834.839.52	1,693.228.02		59.6	30.9	1.324,376.30	17.5	649,863.57
Montana	1.115.962	228.024.60	228,024.60		6.6	500.956.99	500.956.99		5.6	16.1	288.106.23	8.9	98,874.18
Nebraska	1.957.240	142.999.69	142.310.40		8.1	1.649.398.42	1,649,398.42		36.6	22.6	148.397.18	2.6	17.134.00
Nevada	500.051	47.203.38	47.203.38		1.2	398.135.90	398,135.86		2.8	7.0			54.711.76
New Hampshire	706.640					678.365.95	664,365.95		30.1	15.6	42,274.05	.9	
New Jersey	3.190,118	95.888.81	95.888.81		2.1	2.605.324.28	2,551.191.28	30.000,00	34.6	18.7	221,551.42	1.7	321.486.49
New Mexico	1.448.234	227,126.51	227.126.51		6.2	1,046,273.62	1.046.273.62		36.7	22.1	74.917.75	3.9	99.916.12
New York	8.449,487	168.883.17	168.501.87		2.6	7.922.357.60	7.405.925.00	39.000.00	29.4	58.3	207,500.00	1.4	667.560.13
North Carolina	2,380,573	484.567.69	482.530.79		23.9	772.143.79	770.359.51	166.10	8.6	29.7	558,406.53	21.5	569.246.17
North Dakota	1.451.112	36.075.28	36.075.28		5.1	408,020.92	380,835.56	27,185.36	32.8	13.4	411,416.35	17.9	622.784.81
Ohio	4,335.686	104.876.80	90.884.08		2.7	4.131.994.43	3.656.988.43		37.7	49.0	480,463.37	6.2	107.350.12
Oklahoma	2.304.200	144,658.36	144,300.68		5.3	1.671.940.94	1.671.940.94		32.7	32.8	272.521.04	6.3	215.437.34
Oregon	1.526.724	273.519.91	273.519.91		6.8	980,828.42	956.371.09	14.126.97	20.7	16.5	201,586.71	4.4	95.246.29
Pennsylvania	4.854,988	359,702.11	354.020.60		8.9	2.813.365.62	2.755.081.52		36.4	39.8	871,875.12	9.8	874.010.76
Rhode Island	499,677					393.038.32	393.038.32		36.6	6.4			106.638.68
South Carolina	1.364.791	71.523.07	71.523.07		2.9	600.009.63	599.604.62	405.01	30.0	27.4	425,777.29	11.7	267.886.02
South Dakota	1.502,870	160,906.19	160,906.19		7.4	599.369.80	599,369.80		17.2	18.1	355.316.14	12.9	387.277.87
Tennessee	2,123,155	254.800.62	254,800.62		4.8	909.202.94	909,202.94		33.8	11.9	666.450.04	9.3	292.701.40
Texas	6.061,006	884.989.21	826.737.31		37.5	3,471.470.36	3.326.975.68		26.2	62.9	812.961.15	12.6	1.094,331.86
Utah	771,826	472,488.26	461.567.27		10.5	184,521.60	180.354.36		50.6	6.1	10.000.00	.1	119.904.37
Vermont	500.509	41.791.73	41.791.73		1.9	455,811.48	433.717.27	5,838.96	15.9	12.0	25.000.00	.7	
Virginia	2.008.458	220,924.73	211,272.85	9,651.88	7.2	1.425,045.45	1.226.304.17		27.9	13.7	433.856.18	5.3	137.024.80
Washington	1.977.260	565.386.62	552.340.28		15.7	1.403.606.70	1.403,606.70		34.0	16.7			21.313.02
West Virginia	1.342.270	15.323.43	15.323.43		.4	904.466.25	880.120.51		38.3	15.0	259.139.63	4.4	187.686.43
Wisconsin	2,431.220	279.810.98	279.810.98		9.4	1.614,225.18	1.578,929.40		23.7	29.7	572,479.62	12.5	
Wyoming	1.125.332	53.504.69	53.004.69		1.1	850,552.99	850,548.07		30.2	16.1	61.997.83	2.2	159.781.41
District of Columbia	959.235	289.445.89	289.445.89		2.4	680.633.97	663.650.15		47.7	2.3			6.138.96
Hawaii													
TOTALS	114.962.369	10.836.191.26	10.418.615.06	116.878.53	320.0	73.130.094.50	70.618.182.12	383.444.62	31.0	1,106.3	18.477.894.82	342.9	15,447.677.00

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF MAY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2,092.533.00	$ 10.175.87	$ 10,175.87	0.1	$ 366.618.51	$ 366.618.51	19.9	26.8	$ 1.162.648.19	91.3	$ 553.090.43	Alabama
Arizona	625.435.00	40.700.00	40.700.00	6.0	427.644.64	415.517.65	42.5	28.9	66,882.80	7.4	102,334.55	Arizona
Arkansas	1,687.084.00	32.039.78	32,039.78	9.6	849,463.55	849.463.55	24.9	102.2	185.100.21	27.0	620,480.46	Arkansas
California	3.589.691.00	355.186.02	264,830.60	7.9	2.899,373.23	2.459.826.28	34.4	146.0	569.125.32	22.8	295.908.80	California
Colorado	1.718.632.00	496,510.43	495.807.15	74.3	1.135.654.96	1.100,233.89	55.4	100.2	13.641.00	1.2	108.949.96	Colorado
Connecticut	659.120.00				664.915.58	659,120.00	17.3	14.5				Connecticut
Delaware	454.772.00				181,790.00	181.790.00	28.6	1.8	72.547.50	12.2	200.434.50	Delaware
Florida	1.307.958.00	270.184.94	270,184.94	19.8	962.833.57	962,833.57	64.2	49.3	28.739.81	2.5	46.199.68	Florida
Georgia	2,320.973.00	69.600.63	69.600.63	4.2	892,169.85	892.169.85	37.4	72.4	319.217.64	30.1	1.039,984.88	Georgia
Idaho	1.121.562.00	355,160.91	335.426.53	46.9	841,478.63	786.135.47	51.7	98.8				Idaho
Illinois	5.265.960.00	209.925.07	209,925.07	34.3	4.396,264.50	4.396.264.50	26.8	263.0	610.178.45	21.1	49.591.98	Illinois
Indiana	501,892.00				462.227.52	462.227.52	26.6	63.4	39,664.48	5.7		Indiana
Iowa	2.212.245.00	114.654.18	111.300.00	34.6	1.506.766.47	1,434.700.00	45.8	167.4	661.295.00	95.3	4,950.00	Iowa
Kansas	2,522,401.00	290,370.11	290.370.11	6.4	2.236.457.37	2.225.590.41	36.8	156.2	6.440.48	1.7		Kansas
Kentucky	1,879.340.00	214.819.28	214.752.45	31.5	1,521.784.50	1.520,399.26	52.1	177.2	133.879.45	12.2	10,308.84	Kentucky
Louisiana	1.457.148.00	61.627.65	61.627.65	2.2	755.309.16	755.309.16	17.5	35.1	359.846.18	8.9	280.365.01	Louisiana
Maine	842.479.00	511.734.98	505.328.32	48.9	415.432.89	329.202.47	90.0	35.3			7.948.21	Maine
Maryland	891.132.00				522,207.30	508.281.30	52.4	40.5	311.197.00	20.2	71.653.70	Maryland
Massachusetts	488.185.00				469.741.41	469.741.41	54.3	15.2			18.443.59	Massachusetts
Michigan	3.184,057.00	88,500.00	88.500.00	7.3	2.788,300.00	2,788.300.00	17.0	216.3	69.000.00	1.0	238.257.00	Michigan
Minnesota	2,376.415.00	381.183.14	381.183.14	55.9	1.760.625.09	1.742.460.26	22.4	213.5	24.197.67	4.0	228,573.93	Minnesota
Mississippi	1,744,669.00				692,710.94	692.710.94	40.3	76.0	215.115.72	28.4	836.842.34	Mississippi
Missouri	2.923.273.00	118.241.26	118.241.26	37.4	2.607.472.81	2,607.472.81	71.0	452.9	191.946.97	10.2	5.611.96	Missouri
Montana	1.859.937.00	549,982.59	549.982.59	76.5	1.242.345.11	1.242.345.11	6.5	142.4	41.036.97	4.1	26.572.33	Montana
Nebraska	1.957.240.00	103.162.74	103.162.74	50.3	1.927.606.26	1.830.877.77	52.4	229.4	20.499.00	4.0	2.700.49	Nebraska
Nevada	1,130.479.00	187.125.76	187.125.76	14.7	821.374.65	821.374.65	60.7	88.1			127,978.59	Nevada
New Hampshire	477.460.00				518.207.67	477.383.82	65.0	25.6			76.18	New Hampshire
New Jersey	56,550.52				56.550.52	56.550.52	54.4	.5				New Jersey
New Mexico	1.448,234.00	275.981.58	275.981.58	63.8	779,017.95	779.017.95	61.9	236.9	44,141.06	1.9	349.093.41	New Mexico
New York	3.608.768.00	248.021.33	248.021.33	11.0	3.787.900.00	3.350.250.00	23.4	88.6			10,496.67	New York
North Carolina	2.380.573.00	584.574.55	584.374.48	39.9	801,953.56	800.776.92	42.1	88.2	406.981.66	49.3	588.439.94	North Carolina
North Dakota	1.451,112.00				107.151.14	107.151.14	24.3	18.2	419.001.79	99.3	924,959.07	North Dakota
Ohio	3.871,148.00	469.880.00	469.880.00	129.8	3.269,130.00	2,998.354.90	37.8	169.8	278.150.00	5.3	124,763.10	Ohio
Oklahoma	2.304,199.00				1.402.135.25	1,294.165.61	19.8	122.5	992,276.44	148.6	17.756.95	Oklahoma
Oregon	1,526.724.00	183.041.25	175.513.65	15.3	1.326.366.73	1,130.342.61	31.3	77.8	191.739.66	15.3	29.128.08	Oregon
Pennsylvania	7.344.822.00	40,096.00	40.096.00	4.9	6.769.344.52	6.683,681.12	35.8	609.7	460.239.17	44.7	160.805.71	Pennsylvania
Rhode Island	499.677.00				412.465.02	412.465.02	38.3	33.2			87.211.98	Rhode Island
South Carolina	1.364.791.00	19.146.72	19.146.72	.6	1.155,839.36	1.155.839.36	52.3	133.1	180.080.44	20.6	9.724.48	South Carolina
South Dakota	1.502.870.00	73.997.76	73.997.76	35.8	330,244.91	330.244.91	41.5	114.5	259.134.52	96.7	839.492.81	South Dakota
Tennessee	2,123.155.00	84.297.69	84,297.69	8.7	1.003.653.16	1.003.653.16	52.3	80.8	594.059.12	46.9	441,145.03	Tennessee
Texas	6,061,006.00	1.457.031.52	1.101.939.20	302.1	4.904.019.32	4.366,893.06	41.2	470.0	151.045.64	6.5	441.128.10	Texas
Utah	1.048,677.00	509.058.61	489,511.34	104.0	433.810.37	414.425.90	25.4	52.2	102.814.44	8.2	41.925.32	Utah
Vermont	438,880.00				407.764.94	387.501.87	25.3	33.1	51.378.13	3.3		Vermont
Virginia	1.699.920.00	362.097.53	345.013.34	81.5	1.106.881.95	1,044.075.46	51.8	123.5	265,277.35	1.4	45.553.85	Virginia
Washington	1.080.673.00	192,221.60	182.221.60	18.4	864.022.41	864.022.41	33.8	45.4	27,739.30	3.9	6.689.69	Washington
West Virginia	1.118,559.00	5.979.96	5.979.96		909.293.97	909.293.97	29.8	50.7	132,079.37	9.1	71.205.70	West Virginia
Wisconsin	2.431.220.00	230.944.37	230.944.37	7.9	1.953,899.48	1.843,520.84	25.7	140.6	207.404.19	22.2	149.350.60	Wisconsin
Wyoming	1.125.332.00	397.971.86	386.763.00	48.4	650.533.25	635.367.00	35.0	92.7	103,202.00	16.4		Wyoming
District of Columbia	959.234.00	110.619.34	110,619.34	2.0	848.409.36	848.409.36	38.9	5.7			205.30	District of Columbia
Hawaii	187,106.00				177.717.69	177.717.69	29.2	4.9			9.388.31	Hawaii
TOTALS	92,931.302.52	9.705.847.01	9.164.565.95	1.442.9	67.324,881.03	64,572.070.94	37.5	5,831.0	9,968,944.12	1.010.9	9.225.721.51	TOTALS

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF MAY 31, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8.370.133	$ 308.760.85	$ 217.818.81	$ 90.942.04	9.5	$ 6,945.406.26	$ 4.490.795.85	$ 2.454,610.41	40.7	360.0	$ 2.456.509.94	161.5	$ 1,205.008.40
Arizona	5.211.960	1,378.577.19	1.360,030.09		90.1	3,702.486.72	3.093.101.33		46.0	229.7	462,029.70	18.4	296.798.88
Arkansas	6,748.335	422.268.54	335.174,70	87.093.84	22.9	4,223.708.81	3.737.788.36	485,920.45	46.4	245.7	1.590,475.40	73.1	1.084.896.54
California	15.607.354	3.926.408.34	3.239.218.55		100.8	12,576.118.16	10.090.744.58		32.2	389.9	1.483.343.31	42.1	794.047.56
Colorado	6.874.530	2.535.574.82	2.478,483.54		179.1	3,684.498.38	3.649.077.31		39.8	166.4	532,672.87	15.4	214.296.28
Connecticut	2,865.740	48.325.68	48.325.68		.5	2.928.334.05	2.743,617.65	178.920.82	27.7	54.5	68.293.81	.5	5.502.86
Delaware	1,819,088	270.742.30	270,742.30		3.5	1.083.829.70	1.083,829.70		37.6	18.4	218.067.50	17.4	246.448.50
Florida	5.231.834	1.164.597.89	858.871.38	305.726.51	50.5	4.835.251.44	4.099.933.45	734.707.89	57.2	152.0	50.021.56	2.6	223.007.61
Georgia	10.091.185	1,050.226.77	1.050,226.77		56.5	4,403.670.07	4.403,670.07		42.8	273.8	1,445,113.47	100.0	3,192,174.69
Idaho	4.486.249	1.197,486.86	1,160,085.36		124.4	2,949.202.10	2,854.388.65		34.9	211.1	281.334.13	3.8	190,440.86
Illinois	17.570,770	332.285.31	332.285.31		36.2	13.286.822.05	13.286.822.05		29.5	373.5	2,840.344.30	38.2	1.111.318.34
Indiana	10.037,843	42.730.27	42,730.27		.8	6.318.282.33	6.312.939.93		20.8	207.0	2,521.504.20	58.3	1.160.668,60
Iowa	10.055,660	1.322.624.62	1,303.350.00		110.3	7,303.124.01	6,834,075.00		54.0	391.7	1.198.045.00	114.3	720.190.00
Kansas	10.089.604	1.730,374.87	1,730.366.27		193.7	8.680.836.76	8.285,795.08		56.1	403.2	72.865.21	2.4	577.44
Kentucky	7.517.359	471,885.16	467,362.04		48.3	5.062.433.84	5.052.864.92		45.8	408.1	1.102,430.76	46.1	894.701.28
Louisiana	5.828.591	290.099.73	290,099.73		7.1	4,421.858.10	3.915,207.10		30.4	125.0	1,117.985.88	19.5	505.298.29
Maine	3.369.917	601.214.35	593,682.12		50.5	2,566.070.09	2.442.901.42		44.9	93.1	128.235.72	1.6	205.097.74
Maryland	3.564.527					1,573.599.34	1,545.874.59		36.0	57.4	787.113.60	28.1	1.231.538.81
Massachusetts	6.597.100	215.045.03	114,849.13	92.984.24	5.7	5.665.120.15	5.335.360.51	329,759.64	34.4	61.4	802.023.34	2.4	344.867.02
Michigan	12.736,227	332.200.00	332.200.00		11.2	9.918.700.00	9.867.550.00	49,000.00	24.5	471.3	1.311,991.00	46.9	1.224,486.00
Minnesota	10.656.569	3.198.051.73	3.197,958.32		547.2	4,876,645.93	4.807,998.23	50.482.87	25.1	494.4	1.805,298.72	91.9	845.313.73
Mississippi	6.978.675	411.372.98	274,599.14	136.773.84	16.6	5.365.445.39	3.412,916.87	1,913,896.58	36.7	317.4	928,281.95	66.1	2,362,877.04
Missouri	12,180.306	1.385.922.36	1.165.372.23		89.2	8.716.602.89	8.234.848.82	68.548.60	63.2	628.9	1.800.750.48	39.7	979,334.47
Montana	7.439.748	1.649.645.06	1,649.629.06		162.8	5.647.451.89	5.234,650.46	332.801.43	34.9	430.6	428,866.17	61.3	126.602.31
Nebraska	7.828.961	1.776,917.41	1,410,221.26	108.538.00	247.6	7.130.686.03	6,193.414.88		45.9	415.7	204.190.76	15.5	21,134.10
Nevada	4,545.917	1.142.267.43	1.142,267.43		153.6	3.009.591.99	3.009.591.95		35.5	210.7	131,524.90	6.8	262,532.72
New Hampshire	1.909.839					1.849,382.23	1.788.050.97		49.6	52.0	42.274.05	.9	79.513.98
New Jersey	6.346.039	108.524.04	108.524.04		2.3	5,433.931.51	5.224.877.50	169.466.42	28.0	59.8	326.098.63	4.0	686.538.83
New Mexico	5.792.935	2.007.432.80	2.007.432.80		257.4	3.233,180.29	3.217.433.86		42.0	350.6	119.058.81	5.8	449.009.53
New York	22.330.101	746,521.64	646.080.34	43.000.00	21.1	22.981.821.78	20.584,104.18	354.000.00	29.9	377.2	357.697.80	10.0	742.218.68
North Carolina	9.522.293	1.878,508.50	1.580.795.17	295.476.36	134.4	4.486.447.73	4.167.292.36	310.297.46	35.2	534.3	1.975.585.26	202.4	1,798,620.21
North Dakota	5.804.448	906.302.97	906,299.46		409.1	1.901.855.76	1,733.654.69	168.201.07	28.5	393.5	1,530.183.90	325.2	1,634.309.95
Ohio	15.484.592	1.313,572.27	1,297.985.71		151.4	14.149.892.43	13.086,738.33	51.410.00	43.6	386.8	836.491.37	16.5	263.376.59
Oklahoma	9.216,798	805.889.14	804.053.94		66.5	6.579.498.58	6.471.528.94		39.8	384.3	1.313.644.27	162.5	627.570.85
Oregon	6.106,896	1.322.192.00	1,202.453.40		81.0	4.588,964.50	4.209.536.85	72.632.64	33.2	217.5	564,784.70	21.1	130.121.05
Pennsylvania	18.891.004	461.731.13	456,049.62		15.0	15.548.804.45	15.357.459.19		32.8	772.9	1,899.712.12	61.8	1,177.783.07
Rhode Island	1.998.708	18.144.13	18.144.13		.5	1,785.124.92	1,785.124.92		43.1	59.6			195,438.95
South Carolina	5.459.165	276.784.11	276,784.11		24.8	3.760.673.56	3.757.538.93	3.134.63	42.7	345.0	870.179.85	47.1	554.662.11
South Dakota	6.011.479	1.143.920,40	1,124,579.01	19.341.39	184.0	2.832.425.53	2.557.241.37	275.134.16	25.4	410.3	829,307.60	157.8	1.500.351.02
Tennessee	8,492,619	881.422.69	767,285.97	114.136.72	36.5	5.682.044.26	5.220.163.60	461.880,66	48.4	235.2	1.660.490.41	80.4	844.679.02
Texas	24.244,024	5.524,674.03	4.520.738.60		808.7	16,346.993.12	15.044.234.41		36.4	1.033.9	1.749.583.57	80.8	2.929.467.42
Utah	4.194,708	2.058,697.63	2,025.460.66		227.0	1.771.425.54	1.747.873.83		41.9	140.6	181.018,54	8.7	240,354.97
Vermont	1.867,573	132.315.95	131.718,66		9.3	1,681,742.64	1.611.232.11	5.838.96	28.2	81.5	108.612,84	5.0	16.009.39
Virginia	7.416.757	1.144.510.56	1.100.201.51	27,224.86	109.1	5.194.585.92	4.817,898.73	111.852.63	40.2	240.7	1,130,970.51	30.2	367.686.25
Washington	6.115,867	1.509.594.35	1,485,116.93		76.5	4.504.259.64	4.498.018.35	3.356.82	32.7	125.3	96.266.49	5.3	36.465.23
West Virginia	4,474,234	216.185.21	216.185.21		6.8	3.520.551.40	3.490.205.66		45.3	130.4	440.685.14	14.7	327,157.99
Wisconsin	9.724,881	847,704.45	837.401.62	1.190.00	33.6	7.400.648.76	7,081.294.39	21.500.00	31.8	353.5	1,264.338.23	60.6	541,846.76
Wyoming	4.501.327	1.368.044,91	1.238,340.69	80,400.00	213.3	3.017.103.95	2.884,974.47	55.800.00	30.3	395.8	205.611.35	28.6	172,400.49
District of Columbia	1.918.469	400.065.23	400,065,23		4.4	1,529.043.33	1.512,059.51		42.8	8.0			6,344.26
Hawaii	1.871,062	123.221.48	110.214.35	12.994,32	6.3	1.303.971.40	1.502,765.58	251,205.32	23.8	31.4	25.590.00	1.2	232.492,07
TOTALS	394.000,000	52.401.565.17	48,327.860.65	1,415,522,12	5.197.6	288,460.149.71	267.371.061,49	8.914,409.96	37.6	14.311.3	43.297,499.12	2,404.5	35.003,578.74

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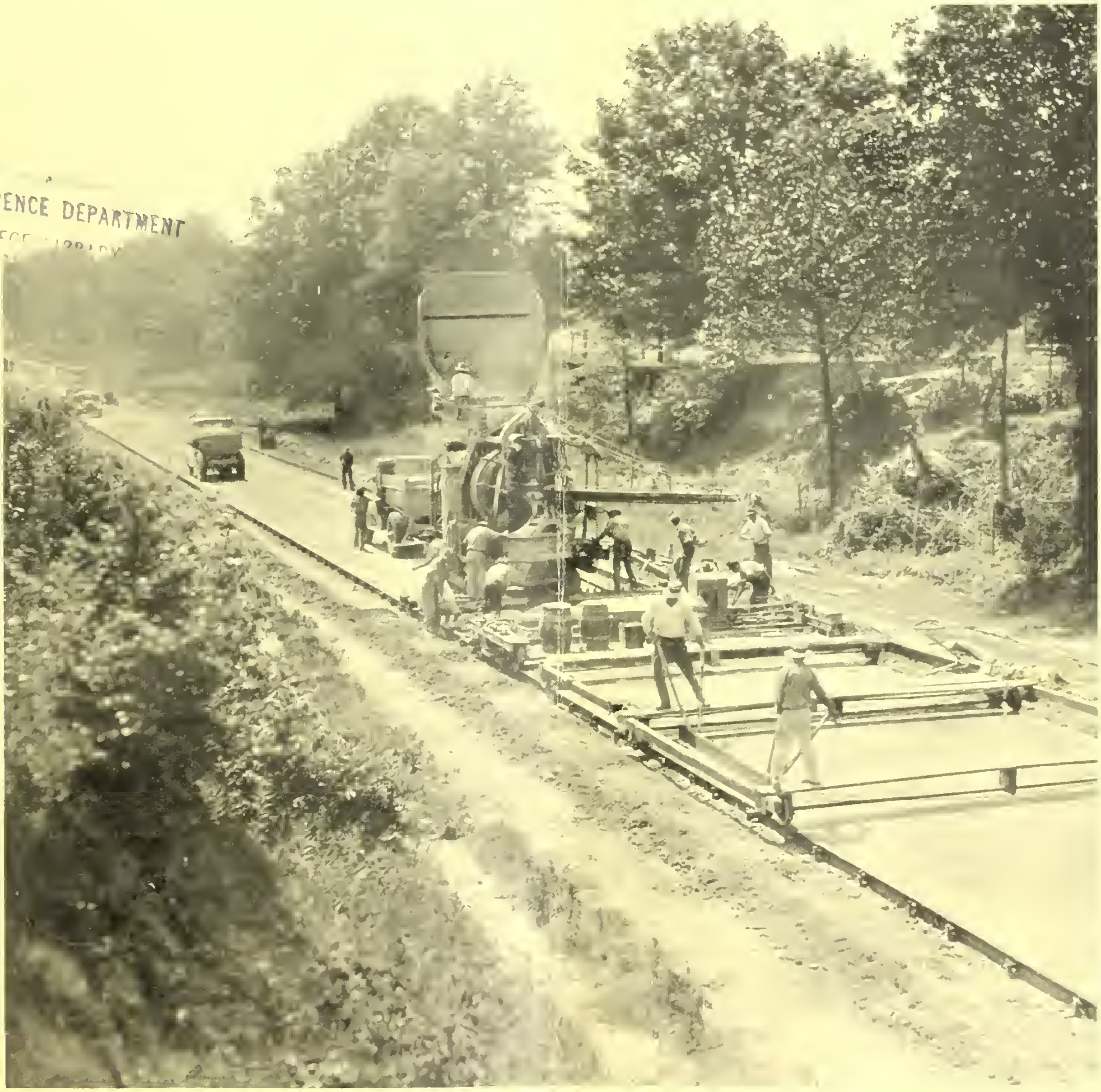

LAYING A CONCRETE ROAD SURFACE

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

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BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 5 July 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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SOME ASPECTS OF PORTLAND CEMENT CONCRETE PAVEMENT CONSTRUCTION

BY THE DIVISION OF MANAGEMENT, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by WILLIAM A. BLANCHETTE, Highway Engineer

STUDIES of production in highway construction have been made by the Division of Management of the Bureau of Public Roads from 1923 to the present year. These studies have included grading and surfacing of nearly all types of highways in practically all sections of the United States.

The number and mileages of concrete roads constructed and the magnitude of the funds invested in them justify considerable study. During 1930 approximately 10,000 miles of portland cement concrete pavements were laid on rural highways of which 8,500 miles were on State systems. In 1930 the average cost per mile of a 20-foot concrete surface, exclusive of engineering, drainage structures, and rough grading, was about $22,500, a total cost of approximately $225,000,000 for the year. A greater efficiency in such large-scale production will result in correspondingly lessened costs to the public.

In the studies here reported, data were collected relative to personnel, equipment, and efficiency of operation. The causes of efficiency on certain projects were analyzed. Between 1923 and 1929 numerous changes were made in types and sizes of equipment used and in methods of construction. From 1929 to June 1934 changes have not been so extensive. This discussion is based upon investigations made during the latter period.

EFFICIENCY IN CONSTRUCTION GREATLY IMPROVED IN RECENT YEARS

The following observations and conclusions are a esult of these studies:

1. The equipment used in concrete surfacing is easonably well standardized as to type, capacity, and umber of units.

2. The number of men employed on a concrete paving ob varies between wide limits. The average personnel, exclusive of truck drivers, on the 34 projects nalyzed numbered 68 men with a minimum of 42 and maximum of 98.

3. The combination of personnel and equipment on oncrete paving projects observed was usually adequate o the handling of the maximum possible production f the key equipment.

4. There is considerable difference in the over-all fficiency with which different contractors operate the ajor or key equipment. The average over-all efficiency of operation of key equipment on projects tudied in 1929 and 1930 was 78 percent, with a minimum of 47 percent and a maximum of 97 percent. The verage efficiency of operation of key equipment on projects studied between 1923 and 1928 was 55 perent, with a minimum of 42 percent and a maximum of 6 percent. There appears to have been an increase i efficiency in recent years.

5. The efficiency of operation of major equipment is a rasonably accurate measure of the efficiency with which the entire paving organization is operated. It is a indication of the type of supervision employed.

6. Unnecessary interference by inspectors tends to lower operating efficiency and to discourage employment of adequate supervision.

7. About 30 percent of the total cost of a concrete pavement is for cement delivered to the project. Twenty-nine percent is for aggregates delivered to the project. Thirty-seven percent of the cost of cement and aggregates delivered is for transportation. The equipment cost is 9 percent and the labor cost is 11 percent of the total cost of a concrete pavement (exclusive of rough grading, etc.) The daily cost for labor and equipment is almost constant regardless of quantity of production. The unit cost for these two items varies almost inversely with the efficiency of operation.

8. The cement factors used on the projects analyzed varied from 1.23 to 2.10 barrels of cement per cubic yard of concrete.

9. The present method of combining the cement, aggregates, and water into concrete does not produce a homogeneous mass in which these ingredients are uniformly distributed throughout the mass.

10. Present methods of placing and finishing the concrete require fairly wet mixtures, resulting in excess water which decreases the potential strength of the concrete.

PERSONNEL AND EQUIPMENT DESCRIBED

The construction of a concrete pavement requires several separate operations. The subgrade must be prepared. The forms must be set in place. Cement, fine and coarse aggregate and water must be delivered to the paver and mixed. The mixed concrete must be deposited on the subgrade, spread, finished, and cured. These major operations are performed on all concrete paving projects.

Minor operations such as the delivery and placing of reinforcing steel, joints, etc., must be performed also. Each operation requires certain pieces of equipment. Table 1 shows the equipment used on 38 concrete paving projects studied during 1929 and 1930. These projects were located in 18 States and represent nearly every section of the United States. The equipment listed in table 1 is typical of equipment used generally in concrete paving. This table shows the average length of haul from the material yard to the paver in miles during the period of the production study.

Trucks were used for hauling batches except on one project where an industrial railway was used. Single-batch trucks were used on 12 projects; 2-batch trucks on 13 projects; 3-batch trucks on 12 projects, and 4-batch trucks on 2 projects on which 2- and 3-batch trucks were also used.

The mixing on all of the projects was done in standard pavers of the 27-E type. A finishing machine was used on all but 5 projects. On these 5 projects, 4 in 1 State and 1 in another, all finishing was done by hand.

Table 2 shows the personnel employed on the 38 projects. On 34 of them the mixing was done by one 27-E paver. On the remaining 4 projects, two 27-E

TABLE 1.—*Summary of equipment used on projects studied in 1929 and 1930*

	Arkansas no. 1	California no. 1	California no. 2	California no. 3	California no. 4	California no. 5	Colorado no. 1	Illinois no. 1	Iowa no. 1	Louisiana no. 1	Louisiana no. 2	Louisiana no. 3	Louisiana no. 4	Maine no. 1	Michigan no. 1	Missouri no. 1	Missouri no. 2	Nebraska no. 1	New Jersey no. 1
GENERAL INFORMATION																			
Length of project, miles	15.4	11.4	8.5	4.4	5.4	5.2	15.6	9.0	8.8	26.8	10.1	6.8	9.5	3.8	9.5	9.8	37.2	14.6	7.7
Width of pavement, feet	18	20	30	30	30	40	18	18	18	20	18	18	18	20	20	20	20	20	20
Average length of haul during study, miles	6.4	2.7	1.6	1.0	10.0	3.6	2.4	3.5	6.4	5.3	4.2	3.5	1.2	2.8	1.6	2.4	2.5	3.3	3.7
FINE GRADING																			
Blade graders, number and length of blade, feet	1-12 1-10	1-12	2-10	1-8	1-8	1-12 1-8	1-6 1-8		1-12	1-12	1-10	1-12	1-4 1-12			1-5 1-12	1-8 1-10	1[1]	1-6
Tractors, number and horsepower	1-30 1-60	1-30 1-60	2-60	1-60	2-30	1-30 1-60			1-60	1-60	1 1-30	1-60	1 1-60			1-60	2-20 1-30 1-60	1-60	1-30
Motor patrols, number and length of blade, feet								1-8	1-10						1-10			1-8	
Scarifiers, number	1	1	1	1	2	2		1	1	1	1	1	1			1	1	1	1
Subgraders, number	1	1	1	1	2	2		1	1	1	1	1	1			1	1	1	1
Subgrade planers, number	1						1	1	1	1	1	1	1	1	1	1	1	1	1
Rollers, number and size, tons	1-10	1-15	1-13	1	1-12	1-10		2	1-5	1-10	1	1-5	1	1-12	1-10	1-3		1-6	1-10
Fresno teams, number	2		1	1	2	2		2		2	1	2	1		1	5	2	3	2
HANDLING FORMS																			
Lineal feet	4,500	8,000	20,000	8,500	16,000	12,000	3,300	3,000	6,800	4,000	4,200	5,000	4,000	4,000	3,000	4,200	3,300	4,500	6,000
Forms, kind	Steel	Steel	Wood	Wood	Wood	Wood	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Wagon teams, number	2								2	1	2	1	2		1	1	2	1	
Trucks, number		1	1	1	1	1	1	1						1					1
Mechanical form trenchers, number	1							1				1	1		1	1		1	
HANDLING MATERIALS																			
Cranes, number and capacity, cubic yards	1-1	1-1	1-1¼	1-1	(2)	(2)	1-1	1-1¼	1-1	1-¾	1-¾	1-1	1-1	1-⅝	1-1	1-1	2-¾	1-1	1-¾
Batcher bins, number	1	1	1	1		1	1	3	1	1	1	1	1	1	1	1	1	1	1
Tractors, number																1			
Cement houses, number			1						1		1	1				1	1		1
Pumps, number	1	2	2	1	1	1	2	1	2	1	1	1	1	1	1	1	1	2	1
Pipe:																			
3-inch, lineal feet			40,000		31,000	27,000		5,000										23,760	
2½-inch, lineal feet		26,500					5,280	16,000	21,000	35,000	6,000	16,000	15,000	6,000		26,400	42,000		21,000
2-inch, lineal feet	26,400			23,000			15,840		31,500		11,000				17,000				
Hose:																			
2-inch, lineal feet	200							400	300			200		200	150	200		300	200
1½-inch, lineal feet				225		600				250	300		100				300		
1-inch, lineal feet		300	200		400														
Service trucks, number		1	1	1	2	3	1	1	2	2	1	2	2	3		1	2	1	1
HAULING BATCHES																			
Trucks:																			
4-batch, number					3			(3)											
3-batch, number		7	7	4	17	18								8	11				7
2-batch, number																			
1-batch, number	17						18		34	29	17	13	11			18	35	27	
Turntables		1	1		1						1	1		1		1	1	1	
MIXING																			
Paving mixers (all 27-E), number	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	2	1	1
FINISHING																			
Strike boards, number and length, feet																			
Finishing machines, number and width, feet	1-18	2-10	1-10	2-10	1-20	2-20	1-18	1-18	1-18	1-20	1-18	1-18	1-18	1-10	1-20	1-20	1-20	1-20	1-10
Longitudinal floats, number and length, feet	2-16	1-16	2-16	1-16	2-16	1-20		1-14	1-10	1-8	1-8	1-10	1-10			1-10	1-10	1-14	
Transverse floats, number and length, feet																			
Rollers, number			1																
Belts or flexible floats, number and length, feet		1-16	1-16	1-16	1-16	1-20	1-18	1-18	2-18	2-18	2-18	2-18	2-18	1-10		1-18	1-20	2-20	
Joint machines, number and width, feet						1-20											1-20		
Hand floats, number			2		2	4		1	7	2	2	2	2		2	2	1	2	3
Straight edges, number								1		2	2	2	2					1	
CURING																			
Burlap, length, feet	1,500	2,000	1,700	1,500	1,200	2,000	500	1,500	2,000	1,000	1,000	800	1,000	700	900		1,800	5,280	
Hose, ¾-inch, feet	200	200	200	200	200	600	350	300	1,000	400	300	200	200	200	300			1,450	
Curing spray apparatus, number								[4] 1		1			1			1	[4] 1		1

[1] Elevating grader. [2] Commercial aggregate plants. [3] All batches hauled by industrial railway. [4] Calcium chloride.

pavers were used either parallel or in tandem. Table 2 shows a wide variation between projects both as to the total number of men employed and the number employed to perform various operations. The major operations are relisted in table 3 which gives, for purposes of comparison, analyses of the numbers of men required for each operation on 34 paving projects using a single paver and those required on 4 projects using 2 pavers each.

The size of the crew necessary for fine grading is affected by several factors: The amount and character of the material to be moved, the amount and kind of equipment used, the efficiency of operation, and the rate at which pavement is being laid. The fine-grading crew varies considerably from job to job as is shown in table 2, with a minimum of 3 men on one project and a maximum of 23 men on another project. The average number of men on all 34 projects was 13.

The handling and setting of forms consists in removing the forms from the finished and hardened pavement, transporting and distributing them where they are to be reset, shaping the form trench, setting, lining up and pinning the forms to the subgrade, and, finally, checking the form line. The number of men used to perform this operation varies considerably, although the methods are more or less standardized. The average number of men required was 11. The chief reasons for variation in the number of men employed are the

TABLE 1.—*Summary of equipment used on projects studied in 1929 and 1930*—Continued

	Ohio no. 1	Oregon no. 1	South Carolina no. 1	Tennessee no. 1	Tennessee no. 2	Tennessee no. 3	Tennessee no. 4	Tennessee no. 5	Tennessee no. 6	Tennessee no. 7	Tennessee no. 8	Texas no. 1	Texas no. 2	Washington no. 1	Washington no. 2	Washington no. 3	Washington no. 4	Washington no. 5	Wisconsin no. 1
GENERAL INFORMATION																			
Length of project, miles	4.9	4.7	19.8	13.8	12.0	14.2	8.1	12.4	10.4	4.7	10.9	13.9	30.4	8.1	7.8	6.4	1.1	6.6	14.7
Width of pavement, feet	30	20	18	18	18	18	18	18	18	18	18	18	18	20	20	18	18	20	20
Average length of haul during study, miles	2.4	2.3	2.2	2.0	2.6	2.3	5.8	8.0	6.0	2.0	2.5	1.9	1.7	0.9	7.3	1.6	4.5	6.4	2.4
FINE GRADING																			
Blade graders, number and length of blade, feet	1-10	2-8	1-8	1-12	1-12	1-12	1-12	1-10	1-10	2-10	1-10	1-10	1-8 1-10	1-12	1-10	1-10	1-10		1-10
Tractors, number and horsepower	1-30	1-20	1-20	1-60	1-75	1-60	1-50	1-60	2-30	1-50	1-50	1-30	1-30 1-60	1-30 1-60	1-30	1-30	1-30		1-30 1-60
Motor patrols, number and length of blade, feet																			
Scarifiers, number	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1
Subgraders, number	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Subgrade planers, number	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rollers, number and size, tons	2	1-10	1-10	2	1-5	1-10	1-10	2	1-10	1-5	1-5	1-3	1-5	1-10	1-12	1-12	1-11	1-12	1-5
Fresno teams, number	1	1		1	1	1	1	1	1	4	3	2		2	1	2		1	1
HANDLING FORMS																			
Lineal feet	2,176	4,600	3,000	5,000	3,500	5,200	3,940	1,600	5,000	5,500	2,060	4,000	4,400	28,600	12,000	15,000	20,000	10,000	38,500
Forms, kind	Steel	Wood	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Wood	Wood	Wood	Wood	Wood	Steel
Wagon teams, number			2		2	1	1		1			1	1						
Trucks, number	1	1		2						1	1			1	1	1	1	1	
Mechanical form trenchers, number		1						1				1							
HANDLING MATERIALS																			
Cranes, number and capacity, cubic yards	2-1	1-2	2-¾	1-1	1-¾	1-1	1-¾	1-1	1-¾	1-¾	1-1	1-1	1-1¼	1-1¼	1-1¾	1-1¼	1-1	1-1¾	1-1¾
Batcher bins, number	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tractors, number	1		1																
Cement houses, number	1		1			1	1	1		1	1	2				1			
Pumps, number	1	1	1	1	1	2	2	1	2	1	1	1	2	3	1	1	1	1	
Pipe:																			
3-inch, lineal feet						10,000								26,400	31,000	15,000	13,200		
2½-inch, lineal feet	10,000	22,000	21,000		5,300	19,040	21,120			21,120	20,000	22,000	40,000					19,000	
2-inch, lineal feet				15,935	15,800			25,000	42,400			10,000							40,000
Hose:																			
2-inch, lineal feet		300		200	200	200				100	150		300	300				300	200
1½-inch, lineal feet	200		300		100				150						550	350	300		
1-inch, lineal feet												175							
Service trucks, number		1	1	1	1	1	2	1	1	1	1	1	3	1			1	1	2
HAULING BATCHES																			
Trucks:																			
4-batch, number																		3	
3-batch, number	12	5						16	10										
2-batch, number			10	10	11	10	13			9	10			5	13	10	10	8	10
1-batch, number			2									15	21						
Turntables				1		1	1	1				1							1
MIXING																			
Paving mixers (all 27-E), number	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FINISHING																			
Strike boards, number and length, feet		1												1-20	1-20	1-20		1-20	
Finishing machines, number and width, feet	2-20		1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18				1-18		1-20
Longitudinal floats, number and length, feet		1-11	1-12	2-16	1-16	2-16	2-16	2-16	2-16	1-10	1-10		1-18	1-16	1-16	1-16	1-16	1-16	1-10
Transverse floats, number and length, feet						1-18	1-18	1-18	1-18					1-20	1-20	1-18	1-18	1-20	1-20
Rollers, number												1		1	1	1		1	
Belts, or flexible floats, number and length, feet			1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-20	1-20	1-18	1-18	1-20		1-16		1-18	2-20
Joint machines, number and width, feet	1-20																		1-20
Hand floats, number	2	2		2	2	2	2	2	2	3	3	2	2	4	9	5	3	5	2
Straight edges, number												1		1	1	1	1	1	
CURING																			
Burlap, length, feet	1,500	1,000	2,000	1,000	825	1,200	2,000	1,000	1,500	1,500	1,500	1,200	1,500	1,000	1,000	800	1,100	1,000	1,000
Hose, ¾-inch, feet	300	300		300	300	200	300	300	1,000	600	300	350	300	700	700	400	450	900	400
Curing spray apparatus, number													1						

method used in trenching, the accuracy with which form trenching is done, the rate at which forms must be set to keep pace with paving, the character of the soil, and the efficiency of form-handling and setting operations.

The average number of men employed in handling materials is 14. This includes the men operating the water-supply system.

The number of men, including truck drivers, truck checkers, dumpers, and turntable operators employed to deliver batches to the paver ranged from 5 to 30. Reasons for this wide variation are length of haul, condition of hauling road, condition and capacity of hauling equipment, rate of paver operation, and efficiency of hauling equipment operation. On an average, 15 men were employed in hauling batches on the 34 projects on which the average length of haul during the period of study varied from 0.9 mile on one project to 10 miles on another, and on which 1-, 2-, 3-, and 4-batch trucks were used.

The men connected with the mixing operation are the foreman, who usually has charge of mixing, placing, finishing, and curing, and the paver operator.

The men employed in finishing, which in this summary includes puddlers, spaders, finishing machine operators, strikeboard laborers, hand finishers on slab

TABLE 2.—*Summary of personnel on 38 concrete paving projects, 1929–30*

	Arkansas no. 1	California no. 1	California no. 2	California no. 3	California no. 4	California no. 5 [1]	Colorado no. 1	Iowa no. 1	Louisiana no. 1	Louisiana no. 2	Louisiana no. 3	Louisiana no. 4	Maine no. 1	Michigan no. 1	Missouri no. 1	New Jersey no. 1	Ohio no. 1 [1]	Oregon no. 1	Tennessee no. 1	Tennessee no. 2	Tennessee no. 3	Tennessee no. 4	Tennessee no. 5	Tennessee no. 6	Tennessee no. 7	Tennessee no. 8	Texas no. 1	Texas no. 2	Washington no. 1	Washington no. 2	Washington no. 3	Washington no. 4	Washington no. 5	Wisconsin no. 1	Illinois no. 1 [2]	Nebraska no. 1	Missouri no. 2 [1]	South Carolina no. 1
Fine grading:																																						
Foremen	1	---	1	---	1	1	---	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	---	1	1	1	1	1	1	1	1	1	1	1
Tractor operators	1	---	2	1	2	2	---	1	1	1	1	1	---	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	---	1	2	1
Blade-grader operators	1	---	1	1	1	2	---	1	1	1	1	1	---	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	---	1	1	1	2	---
Roller operators	1	---	1	---	1	1	---	1	1	---	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	---	1	1	1	1	1	1	1	---	1
Teamsters or drivers	2	---	1	1	2	2	---	2		---	3	2	---	---	5	---	---	---	---	---	---	---	---	---	4	3	2	---	2	1	2	---	1	---	2	3	---	---
Laborers ahead of mixer	8	3	3	---	6	6	6	4	8	2	7	3	11	8	9	6	6	---	7	8	12	9	8	5	15	10	5	10	5	4	1	9	8	6	11	4	4	12
Laborers rear of mixer	---	---	2	---	---	---	5	2	2	2	3	1	---	2	---	---	4	---	2	---	---	---	2	2	2	2	2	4	4	3	3	4	4	2	2	2	4	4
Total	14	3	11	3	13	14	11	12	14	7	17	10	13	14	19	10	14	4	13	12	17	13	14	13	25	19	12	20	15	12	10	17	16	13	18	13	13	19
Handling and setting forms:																																						
Foremen	1	1	1		1	1	---	1	---	---	---	---	---	1	---	1	1	1	1	1	1	1	1	---	1	1	---	---	1	---	1	---	1	---	---	---	---	---
Form setters	3	2	2	2	3	2	2	4	3	4	3	4	1	1	3	4	2	2	3	4	4	3	4	5	4	3	2	2	2	2	2	3	2	1	6	3	1	4
Helpers	3	2	2	2	3	2	2	4	3	3	2	3	1	1	3	3	2	1	---	3	3	3	3	---	3	3	2	2	1	2	1	2	1	1	4	4	8	3
Teamsters	2							2	---	2	2	---	---	1	1	---	2	---	---	2	2	2	2	2	---	---	1	1	---	---	---	---		---	---	2	3	2
Truck drivers		1	1	1	1	1	1	---	2	---	1	1	1	---	---	1	1	1	2	---		---	---	---	1	1	---	---	1	1	1	1	1	2	1	---	---	
Laborers	7	6	14	---	8	10	2	10	1	5	1	4	---	1	2	4	---	2	4	4	4	7	7	1	3	10	4	1	---	3	1	3	1	2	5	5	7	1
Total	16	12	20	5	16	16	7	21	9	14	9	12	3	5	9	13	8	7	10	14	14	16	17	8	12	18	9	6	5	8	6	9	6	6	16	14	19	10
Handling materials:																																						
Foremen at plant	---	---	1	---	1	1	---	1	---	---	---	---	---	1	---	---		1	1	1	---	---	---	---	---	1	---	1	---	1	---	---	1	---	1	1	1	1
Crane operators	2	1	1	1	1	---	1	2	2	1	1	1	1	1	1	1		2	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	2	2	2
Batcher operators	1	1	1	1	1	2	1	1	1	2	1	2	1	1	1	2	2	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	3	1	1	1
Laborers in cars	---	2	---	1	---	---	3	2	---	2	1	2	1	3	3	2	2	---	3	2	2	2	2	2	2	2	3	2	2	1	1	---	1	---	---	---	---	---
Cement handlers, loading	5	---	3	3	5	4	---		2	2	3	4	2	3	3	2	---	---	2	3	3	4	3	3	3	3	2	4	2	---	6	---	---	3	2	---	7	6
Cement handlers, dumping	2	4	3	3	4	4	4	6	3	2	3	2	3	2	2	3	6	---	3	3	3	2	3	3	2	2	2	2	3	3	2	3	3	3	1	7	4	6
Sack shakers, balers	1	1	---	---	1	---	---	---	---	1	---	---		---	1	---	---	---	2	1	---	---	1	1	---	1	---	---	---	---	---	1	1	1	---	---	---	---
Pump operators	1	---	1	1	1	---	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	---	1	1	1	1	---	1
Laborers on pipe line	2	---	---	---	---	2	2	3	---	---	1	---	1	---	2	---	---	---	---	2	4	---	3	---	---	2	---	3	3	2	---	---	2	---	2	2	---	---
Laborers	---	---	2	---	---	3	---	---	---	---	---	1	1	---	1	3	7	---	3	---	2	---	---	---	---	4	3	1	1	1	1	1	1	---	3	2	---	6
Service truck drivers	---	1	---	1	2	2	1	2	2	---	1	---	---	---	1	---	1	---	1	1	1	2	1	1	1	1	1	---	1	---	---	1	---	1	2	1	1	1
Total	14	10	12	11	16	18	13	19	11	11	12	13	11	12	16	14	19	5	18	16	19	13	16	15	12	19	14	17	15	11	13	8	12	12	16	17	16	24
Hauling batches:																																						
Truck foremen	---	1	---	---	---		---	---	---	---	---	---	---	---	---	---	1	---	---	---	---	---	---	---	---	---	1	---	---	---	---	---	---	---	6	---	1	---
Truck drivers	17	7	7	4	20	18	18	34	29	17	13	11	8	11	17	7	12	5	11	11	10	13	15	9	9	10	15	24	5	13	10	10	11	10	2	27	35	11
Truck checkers	1	---		---	---	---	1	1	1	---	1	---	---	---	1	---	---	---	---	1	1	---	---	---	---	---		1	---	---	---	---	---	---	---	---	---	---
Turntable operators	1	1	1	---	1	---	1	1	---	1	2	---	---	---	2	---	---	---	1	---	2	2	1	---	---	---	1	1	---	---	---	---	---	---	8	---	2	1
Truck dumpers	1	1	1	1	2	2	2	1	1	2	1	1	2	1	1	1	4	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	---	1	2	---
Total	20	10	9	5	23	20	22	37	31	20	17	12	10	12	21	8	17	6	13	13	14	16	17	10	10	11	18	30	6	14	11	11	12	11	16	28	40	12
Mixing:																																						
Foremen	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Mixer operators	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1
Total	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	2	3	2

Finishing:																																						
Foremen	1																	1	1			1					1	1							1			
Puddlers	4	3	5	5	4	5	2	4	2	3	3	3	5	4	4	5	5	2	3	4	3	3	3	3	2	4	4	7	5	3	4	3	3	3	6	2	6	5
Spaders		2			1	2											2								2	2	2										6	
Finishing-machine operators	1	2	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2		1	1	1	1	1	1	1	1	1	1				1		1	1	1	1	1
Strikeboard laborers																		2							2	6			2	2	2	4	2				4	
Finishers, floating slab	4	4	9	4	10	6	4	2	7	2	4	2	4	2	2	4	2	3	4	4	4	4	4	4	5	4	2	4	4	7	5	2	7	4	2	4	6	2
Finishers, joints and edging	2	5	4	3	7	6	2	3						1	2		3	3				1					1	2	2	2	2	2	2	4	1	6	1	3
Total	12	16	19	14	23	21	9	10	10	6	8	6	10	8	9	10	14	11	9	9	8	10	8	8	12	17	11	15	13	14	13	12	14	12	11	13	24	11
Setting steel:																																						
Laborers, reinforcement		3	4	2	5	7		1						4		2	2										2	3						3				
Laborers, longitudinal joints	2								2	2	2	2	4		1			4	2	2	2	2	1	2	1	2	1	1						2	1	1	2	
Total	2	3	4	2	5	7		1	2	2	2	2	4	4	1	2	2	4	2	2	2	2	1	2	1	2	3	4						5	1	1	2	
Curing:																																						
Foremen		1			1	1	1												1	1					1	1	1		1	1								
Laborers on burlap	2	2	2	2	2	2	3	2	2	2	2	4	1	2			2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	5	1	2	2	2
Laborers, covering and sprinkling	8	5	9	5	10	9	9	12	2	2	5	2	1	3	2	1	5	3	12	2	9	5	6	11	4	3	7	9	11	2	3	2	3	4	2	3	2	8
Total	10	8	11	7	13	12	13	14	4	4	7	6	2	5	2	1	7	5	15	5	11	7	8	13	7	6	10	12	14	5	5	4	5	9	3	5	4	10
Supervision:																																						
Superintendent	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Timekeepers	1	1	1	1	2	1	1	2	1	1	1	1	1	1	2	1	2	1	1		1	1	1	1	1	1	1	1	2	1				1	1	2	1	1
Total	2	2	2	2	3	2	2	3	2	2	2	2	2	2	3	2	4	2	2	1	2	2	2	2	2	2	2	2	3	2	1	1	1	2	2	3	2	2
Miscellaneous:																																						
Laborers	3			1	2		2		2			1			1	1	12				7				7		1			2		3		1	4	1	1	1
Watchmen	2						1	1	1	1		1		1		1	2		1	1	2	1	1	1	1	1	2	1	1	1					2	2	1	
Mechanics	1	1	1	1	2									1																				1	1	2	4	1
Waterboys	1							1		1		1	1	1	1	1	2	1	2	2	2	2	2		2	3		1		1			1		2	1		1
Total	7	1	1	2	4		3	2	3	2		3	1	3	2	3	16	1	3	3	11	3	3	1	10	4	3	2	1	4		3	1	2	9	6	6	3
Total, excluding truck drivers, steel crew, and miscellaneous	73	56	79	45	89	88	61	84	54	49	61	52	45	49	64	53	74	37	71	61	77	66	69	62	73	84	63	80	68	55	51	54	57	57	71	68	86	79
Total, excluding truck drivers and steel crew	80	57	80	47	93	88	64	86	57	51	61	55	46	52	66	56	90	38	74	64	88	69	72	63	83	88	66	82	69	59	51	57	58	59	80	74	92	82
Total, excluding truck drivers	82	60	84	49	98	95	64	87	59	53	63	57	50	56	67	58	92	42	76	66	90	71	73	65	84	90	69	86	69	59	51	57	58	64	81	75	94	82
Grand total personnel	99	67	91	53	118	113	82	121	88	70	76	68	58	67	84	65	104	47	87	77	100	84	88	74	93	100	84	110	74	72	61	67	69	74	97	102	129	93

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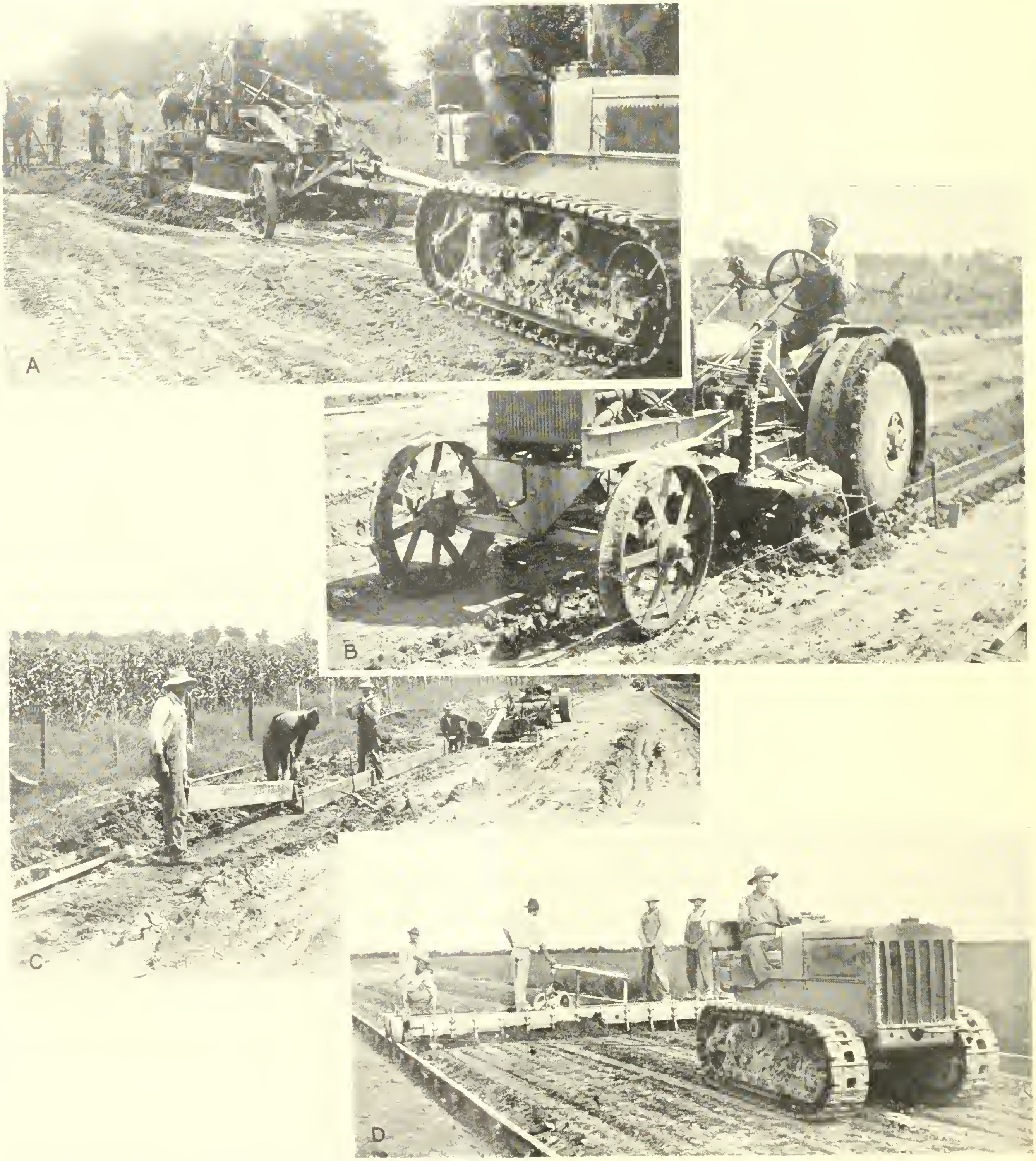
[1] 2 pavers were used on project.

[2] 2 pavers were used and an industrial railway was used for hauling batches. Under personnel for "Batch hauling" are listed 6 operators, 2 brakemen, and 8 in section crew.



A, shaping the subgrade with a tractor-drawn grader; *B*, excavating trench for forms; *C*, setting and lining up forms; *D*, the "subgrader" does the final shaping, leaving excess material in furrows for removal by hand shovels or fresnos.

STEPS IN SHAPING THE SUBGRADE.

and on joints, varied from a minimum of 6 to a maximum of 23 with an average of 11.

Setting steel, which includes both the longitudinal steel joint and reinforcing steel, required an average of 2 men on each of the 34 projects. The number varied from 1 to 7 for individual projects. On several projects neither longitudinal joint steel nor reinforcing steel was used.

The number of men employed in curing the concrete varied from 1 to 15, depending on the method of curing, the amount of slab to be cured and the efficiency with which the curing operation was performed. An average of 8 men was used for this work.

TABLE 3.—*Analysis of number of men required for different operations*

Operation	For 34 projects using a single paver							Average number of men on 4 projects using 2 pavers
	Number of projects employing numbers of men between						Average number of men	
	0–5	6–10	11–15	16–20	21–25	26–up		
Fine grading	3	4	18	8	1		13	15
Handling and setting forms	4	15	8	6	1		11	15
Handling materials	1	2	20	10	1		14	17
Hauling batches	1	8	12	6	3	4	15	23
Mixing	34						2	3
Finishing		16	14	3	1		11	18
Setting steel	34						2	3
Curing	13	12	9				8	7
Miscellaneous	30	3	1				3	8
Supervision	34						2	2
Grand total all personnel							81	111
Total exclusive of truck drivers							68	90

TABLE 4.—*Labor and equipment required on average concrete paving project as estimated from study of 34 projects*

FINE GRADING

	Number and type of equipment units	Number and class of men employed
Blade grader	1, 8 to 12-foot blade	1 foreman
Tractors	1, 30 to 75 horse-power	1 tractor operator
Scarifiers	1	1 blade grader operator.
Subgraders	1	1 roller operator.
Subgrade planers	1, heavy, metal	2 teamsters.
Rollers	1, 3 to 15-ton	2 laborers in rear of paver.
Fresnos	2, 3-foot	
Fresno teams	2, 2-horse	5 Laborers ahead of paver.
Total		13

HANDLING AND SETTING FORMS

Forms, lineal feet	4,300 steel	1 form foreman.
Teams	1, 2-horse	2 form setters.
Trucks	1	2 form setters' helpers.
Form trenchers	1	1 teamster or truck driver.
		1 teamster's helper
		4 laborers.
Total		11

HANDLING MATERIALS

Crane	1, ½ to 2 cubic yard capacity.	1 plant foreman.
Batcher bins	1	1 crane operator.
Cement house	1	1 batcher operator
Pumps (water)	1 to 3	2 laborers in cars.
Pipe line, lineal feet	25,000, 2, 2½, 3-inch	6 cement handlers, load, dump.
Hose, lineal feet	250	
Truck service	1	1 laborer on pipe line
		1 pump operator.
		1 truck driver, service.
Total		14

HAULING BATCHES

Trucks	Variable 1 to 4 batches	13 truck drivers, variable
Turntable	1	1 truck dumper.
		1 turntable operator or truck checker
Total		15

MIXING

Pavers	1, 27-E	1 foreman
		1 paver operator
Total		2

TABLE 4.—*Labor and equipment required on average concrete paving project as estimated from study of 34 projects*—Continued

FINISHING

	Number and type of equipment units	Number and class of men employed
Finishing machine	1	4 puddlers and [illegible]ers.
Floats	1 to 3	1 finishing machine operator.
Belts	1	3 hand finishers, slab
Small tools		2 hand finishers, joints
Bridges	4	1 hand finisher, edger
Total		11

SETTING STEEL

		2 laborers.

CURING

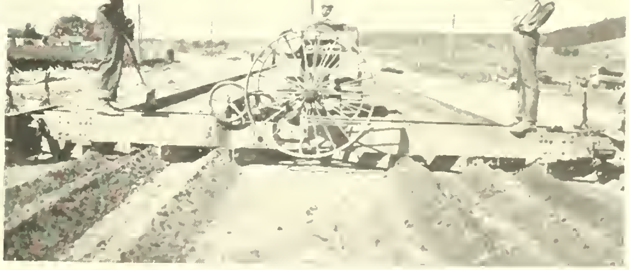
Burlap, road feet	1,300	2 laborers, burlap
Hose, ¾-in., lineal feet	400	6 laborers, covering
Curing agent apparatus		
Total		8

MISCELLANEOUS

		1 watchman 1 water boy 1 mechanic.
Total		3

SUPERVISION

		1 superintendent. 1 timekeeper.
Total		2
Total exclusive of truck drivers		68
Grand total		81



SHAPING THE SUBGRADE.

The equipment and the personnel on the average project, as judged from 34 projects, are shown in table 4, which gives the approximate distribution of personnel performing each operation. This table shows an average of 68 men employed to operate a modern paving outfit exclusive of the operators of hauling equipment. "Miscellaneous" as used in table 4 includes watchman, water boy, and mechanic. "Supervision" includes the superintendent and timekeeper.

Table 2 shows that the total personnel exclusive of truck drivers and steel crew on the paving projects employing a single 27-E paver varied between 38 and 93, a difference of 55 men.

In general, the number of men employed to operate a concrete paving outfit should be sufficient to perform all of the operations when the paver is working at maximum production. Considerable physical exertion is required of workers and assignments should be such that the work can be accomplished by uniform sustained effort and without injury to the men.

The type of supervision exercised over workers varies considerably. Some operations require a definite number of men regardless of the amount of work they have to do. Utilization of the capacity of workmen performing various operations may vary considerably. Again, the number of men that the contractor must employ to perform an operation may be and sometimes is regulated by arbitrary requirements of the engineer or inspector rather than by the amount of work to be done.

The number of men employed is regulated by a combination of the following influences: The maximum possible rate of production of the paver, the volume and character of fine grading, the lineal feet of transverse joints to be finished per square yard of pavement, methods employed, arbitrary requirements, type of supervision given, and extent to which machinery is used. It is believed that the combination of personnel and equipment employed on the majority of projects studied was sufficient to handle full paver production, and that the personnel in many instances was more than sufficient.

NO CONSISTENT RELATION FOUND BETWEEN NUMBER OF MEN EMPLOYED AND EFFICENCY OF OPERATION

To analyze the interrelation that may exist between number of men employed, maximum possible production, and over-all efficiency of paver operation, table 5 has been prepared, based on 23 of the projects studied. The information contained in this table is shown also in figure 1. There is a general relation between the number of men employed and the maximum possible rate of production although this relation is by no means definite. The relation between number of men and efficiency of paver operation is even less definite, showing that there are other factors besides production and efficiency which regulate the size of a working force.

TABLE 5.—*Comparison of number of men employed, over-all efficiency, and maximum possible production*

Project	Men employed exclusive of truck drivers and steel crew	Over-all efficiency, percent	Maximum possible production in cubic yards per hour [1]
Maine no. 1	46	66.4	40.7
California no. 3	47	47.4	50.6
Louisiana no. 2	51	82.1	39.6
Washington no. 3	51	81.8	42.5
New Jersey no. 1	56	76.0	38.6
Louisiana no. 1	57	87.2	41.0
Washington no. 4	57	96.8	51.5
Washington no. 2	59	87.9	51.2
Louisiana no. 3	61	80.3	44.0
Tennessee no. 6	63	86.4	44.7
Colorado no. 1	64	87.4	51.1
Tennessee no. 2	64	81.8	52.4
Louisiana no. 4	55	91.0	43.7
Texas no. 1	66	50.9	52.8
Tennessee no. 4	69	65.6	49.4
Washington no. 1	69	93.5	50.2
Tennessee no. 5	72	83.2	44.0
Nebraska no. 1	74	79.6	47.7
California no. 2	80	95.3	49.6
Texas no. 2	82	75.7	58.6
Tennessee no. 8	88	59.1	48.6
California no. 4	93	95.5	59.4
South Carolina no. 1	93	90.1	34.3

[1] The maximum possible production is regulated by the specified mixing time, the size of batch and the time constants of the paver for charging and discharging.

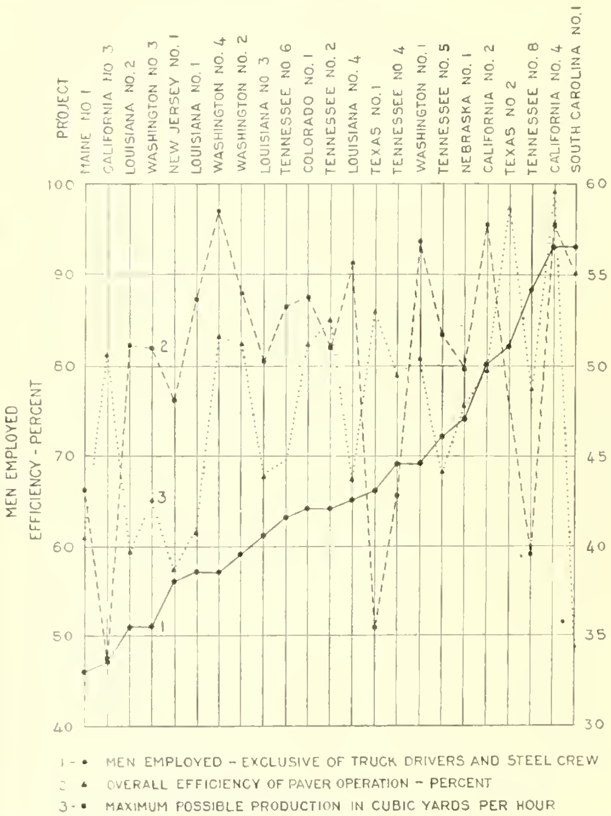
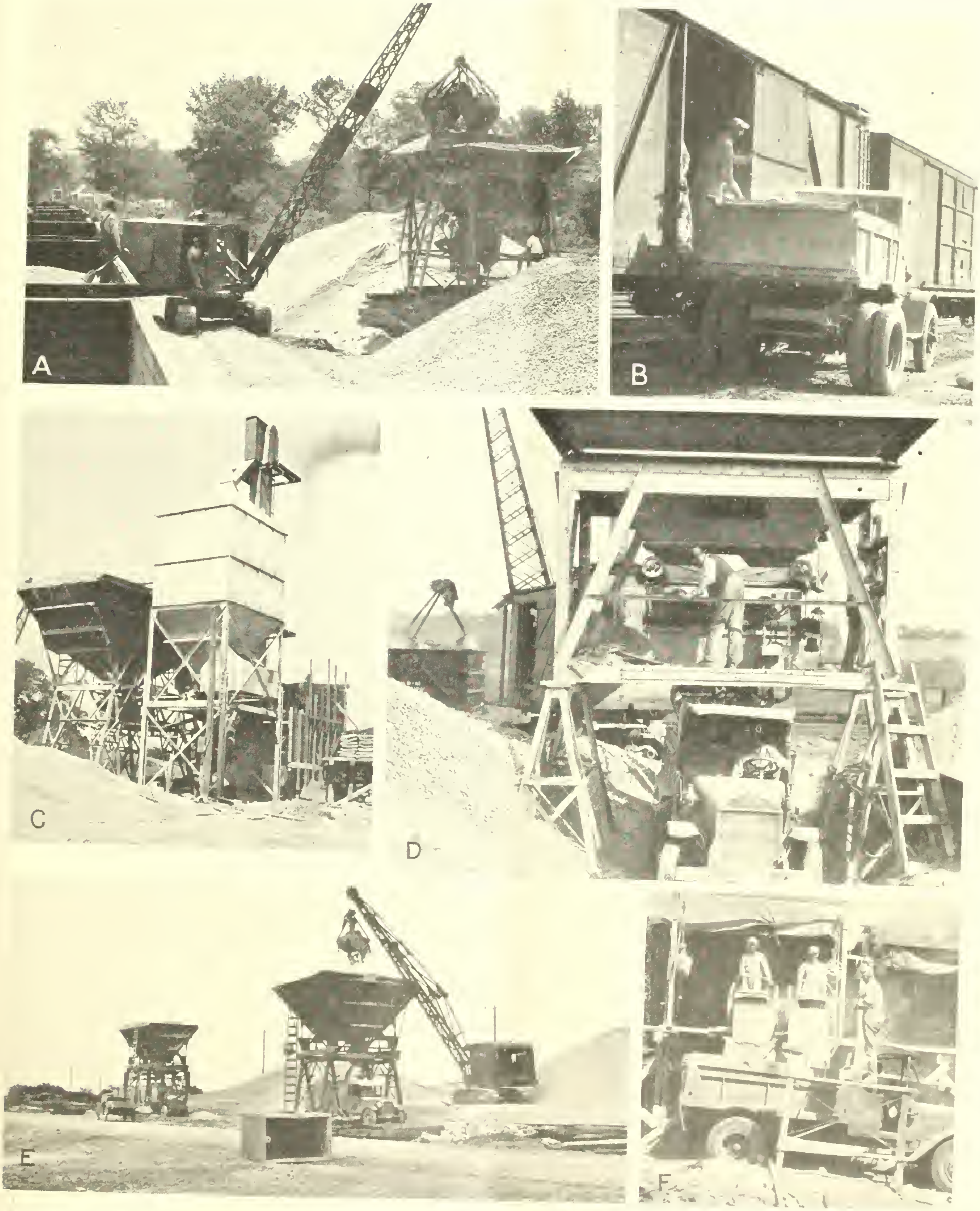


FIGURE 1.—RELATION BETWEEN SIZE OF FORCE, EFFICIENCY AND PRODUCTION.

TABLE 6.—*Comparison of number of finishers (finishing machine operator, spaders, and puddlers), lineal feet of transverse joint per square yard of pavement and maximum possible production*

Project	Number of finishers including finishing machine operator, spaders, and puddlers	Lineal feet of transverse joint per square yard	Maximum possible production in cubic yards per hour
Louisiana no. 2	6	None	39.6
Louisiana no. 4	6	None	43.7
Louisiana no. 3	8	None	44.0
Tennessee no. 3	8	0.018	48.0
Tennessee no. 5	8	.018	44.0
Tennessee no. 6	8	.018	44.7
Michigan no. 1	8	.09	44.9
Tennessee no. 1	9	.018	49.0
Tennessee no. 2	9	.018	52.4
Missouri no. 1	9	.09	36.8
Colorado no. 1	9	.15	51.1
Iowa no. 1	10	None	43.4
Louisiana no. 1	10	None	41.0
Tennessee no. 4	10	.018	49.4
Maine no. 1	10	.23	40.7
New Jersey no. 1	10	.26	38.6
Texas no. 1	11	.11	52.8
South Carolina no. 1	11	.22	34.3
Oregon no. 1	11	.45	40.6
Tennessee no. 7	12	.018	49.5
Arkansas no. 1	12	.18	47.5
Wisconsin no. 1	12	.18	44.0
Washington no. 4	12	.45	51.5
Nebraska no. 1	13	None	47.7
Washington no. 1	13	.45	50.2
Washington no. 3	13	.45	42.5
California no. 3	14	.45	50.6
Washington no. 2	14	.45	51.2
Washington no. 5	14	.45	52.7
Texas no. 2	15	.11	58.6
California no. 1	16	.45	52.0
Tennessee no. 8	17	.018	48.6
California no. 2	19	.45	49.6
California no. 4	23	.45	59.4

Table 6 gives the relation between the number of finishers (finishing machine operator, spaders, and puddlers), the lineal feet of transverse joint per square



A, crane unloading aggregates from cars to batcher bins or stockpiles as conditions require; *B*, unloading cement from cars to batch compartments of trucks. *C*, bin for handling bulk cement and batcher plant. *D*, batcher plant; *E*, a good plant arrangement; *F*, handling bulk cement in "buggies."

ARRANGEMENTS FOR HANDLING CEMENT AND AGGREGATES.

yard of pavement and the maximum possible paver production on 34 projects. Figure 2 also shows this information. No direct relation between these factors is evident.

EFFICIENCY OF PAVER OPERATION IS GENERALLY AN INDICATION OF EFFICIENCY OF ENTIRE ORGANIZATION

The efficiency with which concrete paving is placed is indicated by the studies. It is true that the efficiency with which the paver is operated may or may not measure the efficiency of the paving outfit as a whole. The efficiency of the entire organization is of primary interest to the contractor in that it regulates his unit costs for personnel and equipment. It sometimes happens that, although the paver operates with a high degree of efficiency, it does so with an oversupply of hauling equipment. Other operations than hauling may also be over-equipped or over-manned. It may happen that the personnel and equipment for hauling, subgrade preparation, and other operations have a high degree of efficiency, while the paver has a low degree of efficiency. Or it may be that the paver operates at a consistently low rate, but because of that consistency the production can be handled by a reduced personnel. These conditions are the exception rather than the rule.

In general, the efficiency of the paver is a close indication of the efficiency of the entire organization which is in turn an index of the type of supervision employed. The contractor or superintendent who operates the paver efficiently is likely to be equally efficient in all operations. Similarly, inefficiency in paver operation is often attended by inefficiency in most other operations.

The paver is the key equipment on a concrete paving project and should set the pace for the entire paving organization. It has a maximum capacity of a definite number of batches per hour for the specified mixing time. It cannot exceed this production. When the production of the paver falls below this maximum number of batches the efficiency of the organization in general is lowered.

A definite number of men is required to operate the equipment and to perform nearly every operation. This number of men cannot be changed as the rate of production changes. The number required to operate the outfit at maximum production of the key equipment must be employed, for on the most inefficient jobs studied, there were times during nearly every day when the paver was operating at close to its maximum production.

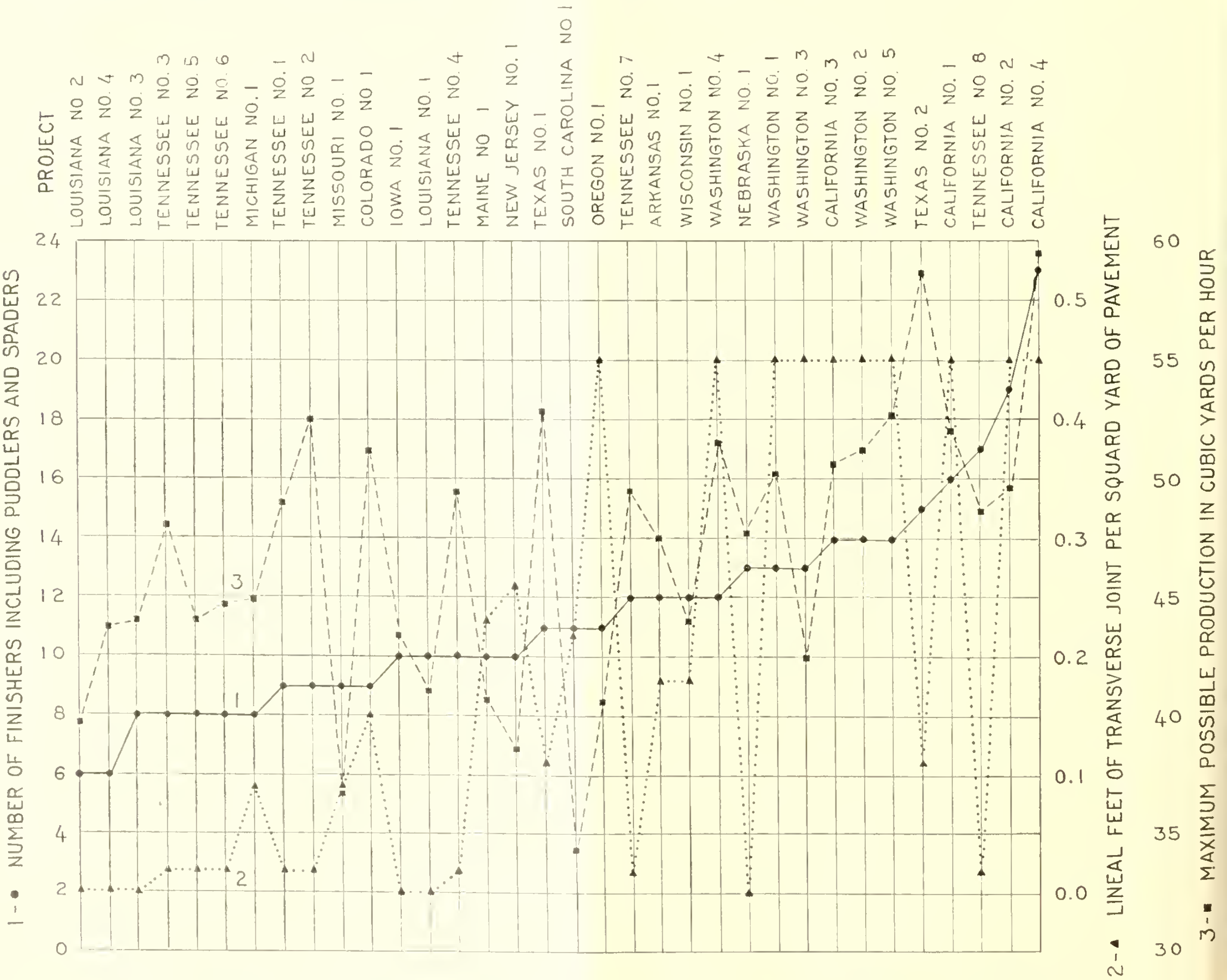


Figure 2.—Relation Between Number of Finishers, Joint Spacing and Possible Production.

Failure of outfits to maintain a high rate of production was not the result of insufficient personnel, but of intermittent delays of varying lengths. A high rate of production requires no greater rate of physical exertion on the part of workers than does a low and fluctuating rate of production.

Before discussing the efficiency of operation of major equipment, an outline will be given of the manner in which efficiency was determined. An engineer with one or more assistants was assigned to the project to be studied. In general, the duration of the study was from 1 to 2 months. During the study an accurate record was kept of the total available working time. The term "available working time" is defined as the time a crew was actually on the job, or the time it would have been on the job had there been no interference by the elements or other contingencies, consideration being given to the customs of the region and the practices of the contractor in regard to length of working day, holidays, etc. If a 9-hour day is customary with 7 hours work on Saturday, and holidays off, the available working time for a week in which no holiday occurs, will be 52 hours plus any overtime, regardless of how much time was actually lost because of rain, breakdowns, or other causes.

An accurate record was kept of all major delays. The term "major delays", as used throughout this report, indicates a delay of 15 minutes or more during the available working time. A delay of less than 15 minutes is termed a "minor delay." The division between major delay and minor delay at 15 minutes is chosen arbitrarily. In general, the major equipment will cease to operate during a major delay or the outfit may be shut down entirely as is usually the case during delays due to rain or wet subgrade. During the shorter major delays the entire organization may be on the job and drawing pay. The total available working time minus the total major delays gives the time the major equipment actually operated.

Minor delays are intermittent interruptions that range from a few seconds up to 15 minutes. Such delays are determined by stop-watch studies of operations. A stop-watch study period was usually of 1 hour's duration. From 2 to 4 such studies were made each day that the paver operated. The results of 2 stop-watch studies, 1 on a project operating with high efficiency and the other on a project operating with low efficiency, are shown in tables 7 and 8.

PREVENTABLE DELAYS FOUND ON MANY PROJECTS

Analysis of these tables shows characteristics of paver operation and the factors affecting the rate of production. The production of a batch of concrete consists of three operations: Raising the paver skip to charge the drum, mixing the batch, and discharging the batch from the drum to the paver bucket. In correct operation the raising of the skip overlaps the discharge of the preceding batch. Whenever the paver ceases to perform one of the three operations its efficiency is lowered. The project reported in table 7 was operated with high efficiency. With a mixing cycle of 74.1 seconds, representing the time to charge, mix, and discharge, the maximum production possible was 48.5 batches per hour. The over-all efficiency on this project during the entire production study was 96.8 percent.

Table 7.—*Result of typical stop-watch study of project operating with high efficiency*

[Drum revolutions, 16.5 per minute]

Charge	Mix	Discharge	Charge	Mix	Discharge	Delay due to: Operator	Delay due to: Mechanical causes	Delay due to: Miscellaneous causes	Delay due to: Split discharge
Sec.	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec*	*Sec.*	*Sec*	*Sec.*
11	59	5	10	60	2	6	8	22	
10	59	5	11	61	3	3	38		7
10	58	2	11	61	3	1			
10	60	2	11	61	3				
10	61	3	10	61	2				
11	61	3	10	62	5				
11	61	3	11	58	3				
11	61	3	10	60	2				
11	60	2	11	62	2				
10	61	3	10	62	2				
10	60	5	11	62	3				
10	59	1	11	60	2				
10	59	2	11	62	5				
10	60	2	10	61	3				
11	61	5	11	62	2				
10	61	2	11	62	2				
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11	61	3							
11	60	2							
11	61	3							
11	61	2							
10	61	3							
10	61	3							
10	60	5							
11	60	1							
10	61	3							
10	61	5							
11	61	3							
11	61	2							
10	62	5							
11	61	4							
10	61	2							
Total			494	2,913	140	10	46	22	7
Average			10.5	60.7	2.9				

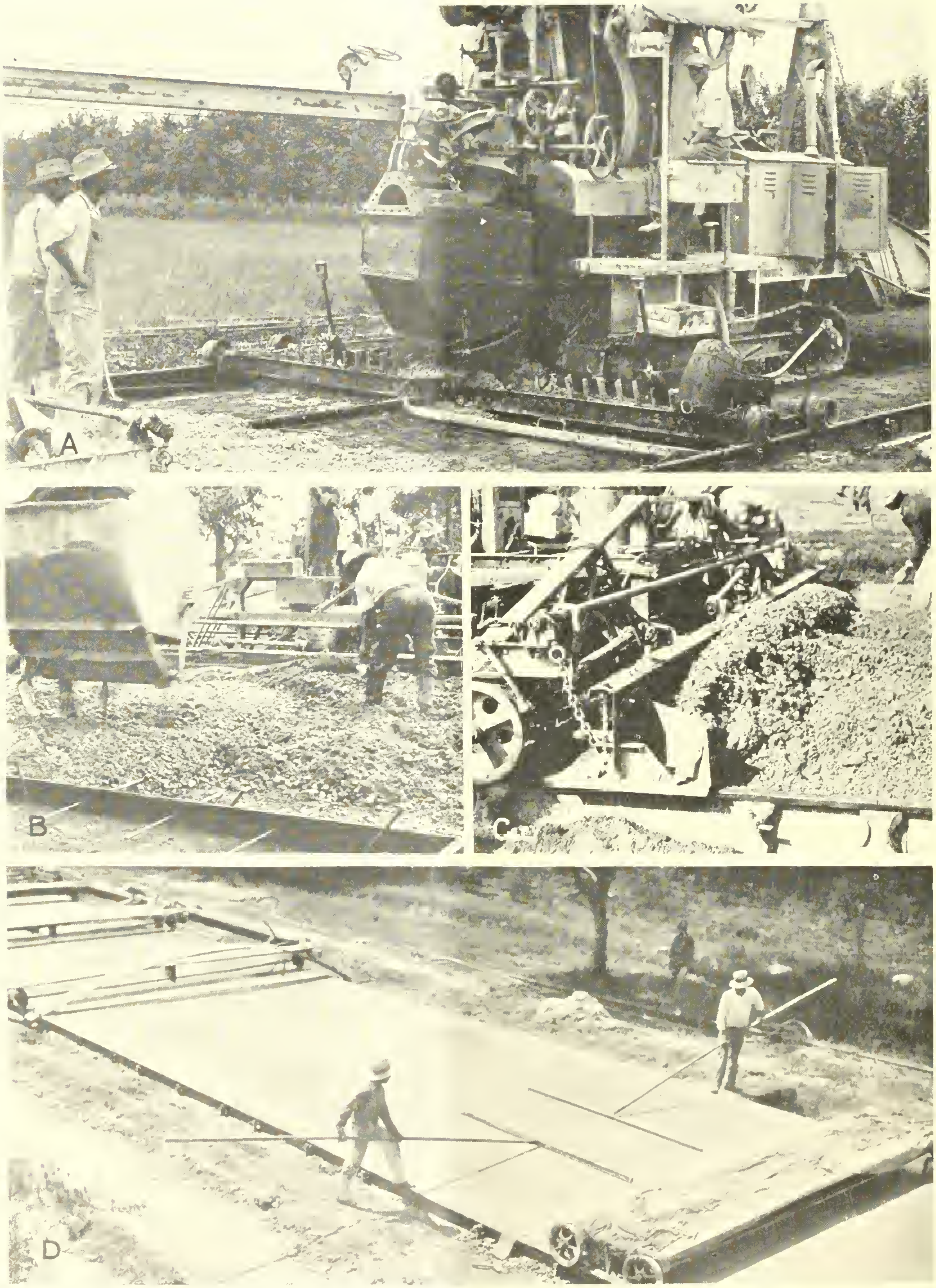
Length of study, 60.53 minutes.
Number of batches mixed, 48.
Total time lost, 85 seconds or 2.3 percent.
Time per batch, 74.1 seconds.

Table 8.—*Result of typical stop-watch study of project operating with poor efficiency*

[Drum revolutions 15.5 per minute]

Charge	Mix	Discharge	Charge	Mix	Discharge	Delay due to: Split discharge	Delay due to: Dumping or turning	Delay due to: Subgrade unprepared	Delay due to: Operation of hauling equipment	Delay due to: Moving turntable	Delay due to: Changing hose
Sec.	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*
9	64	3	9	62	3	25					
9	62	3	9	62	3	27	25				102
9	62	3	9	63	3	26	24				51
9	63	3	9	63	3	24		87			
9	64	3	9	62	3	23					
9	62	3						70			
8	61	3							28		
9	62	3							27		
8	62	3				21					
8	62	3				17		22			
9	68	3				16					
9	63	3								251	
9	62	3				18					
8	62	3				21					
8	62	3						27			
8	62	3						19			
9	63	3				21					
8	62	3						19			
9	62	3						15			
8	62	3						31			
8	62	3							24		
9	62	3				13					102
9	63	3									
Total			213	1,750	84	252	49	290	79	251	[illegible]
Average			8.7	62.5	3.0						

Length of study, 59.2 minutes
Number of batches mixed, 28
Total time lost, 24.6 minutes or 41.5 percent
Time per batch, 74.2 seconds



A, a standard type of paver with subgrade planer attached for smoothing irregularities in subgrade; *B*, depositing concrete on subgrade; *C*, finishing machine in operation; *D*, "straight-edging" the surface.

MIXING AND PLACING CONCRETE.

Table 8 shows stop-watch data taken on a project where the efficiency was low. Small intermittent delays ranging from a few seconds to several minutes account for the low efficiency. Nearly all of the delays could have been eliminated under good supervision such as was found on the first job mentioned. The mixing cycle was 74.2 seconds. The maximum production could have been close to 48 batches per hour. During the study period the production rate was 28.4 batches per hour. The over-all efficiency during the entire period of the production study was 50.9 percent.

Delays of 15 minutes or more occurring during a stop-watch study, were recorded as major delays and were excluded from the stop-watch study period. Periods of study were of such length and at such times that the minor delays recorded are typical of those occurring throughout the working day. The total minor delays recorded during study periods for a day were extended to cover the working time for that day. The time that the major equipment actually operated minus the minor delays is considered to be the time of operation at full efficiency.

Both the major and minor delays are divided into two classes. Class A delays, in general, include those time losses arising from the weather and other causes which could not have been anticipated and prevented under good management. The class B delays are those which should have been eliminated under good management, due allowance being made for conditions affecting the particular project.

The efficiency of operation of major equipment is indicated by expressing the time that the major equipment actually operated at full efficiency as a percentage of the time that it could have operated at full efficiency had all class B or avoidable delays, both major and minor, been eliminated. There are factors which may affect efficiency and which are not taken into consideration in this method of determining over-all efficiency. The specified mixing time is one of them. The operations which must be performed during the mixing period, such as movement of hauling equipment at the paver, dumping batches, filling water tank, changing hose, preparing subgrade in rear of paver, making provision for joints, and placing steel, are less likely to cause delays to the paver when it is operating with mixing time of 75 or even 60 seconds, than when operating with a 50-second mixing time. A paving outfit with a full season's work ahead of it is in a much more advantageous position and has a greater incentive to use a better type of equipment and more specialized personnel, and to attempt efficient operation than is the outfit at work on a project of only a few weeks' duration. This advantage is not generally appreciated as is evident from table 9 and figure 3, which show a lack of relation between length of project and over-all efficiency of operation of major equipment on 24 projects.

Another factor in this method of determining over-all efficiency is the ability of observers to classify delays as avoidable or unavoidable according to the definitions previously given. A classification of this kind is essential if efficiency of operation is to be determined with any high degree of accuracy. The total available working time is no indication of the time in which it was possible to operate, when delays beyond the control of the contractor have occurred or when it would not be profitable to avoid delay. The observers in these studies had investigated paving projects and are thought to have been well trained for the work. The classifications made by the observers depended on judgment and therefore may not always be correct but there was no practicable way of eliminating the personal factor.

Table 9.—*Comparison of over-all efficiency and length of project*

Project	Over-all efficiency	Length of project
	Percent	*Miles*
California no. 3	47	4.4
Texas no. 1	51	13.9
Tennessee no. 8	59	10.9
Tennessee no. 4	66	8.1
Maine no. 1	66	3.8
Texas no. 2	76	30.4
New Jersey no. 1	76	7.7
Nebraska no. 1	80	14.6
Louisiana no. 3	80	6.8
Tennessee no. 2	82	12.0
Washington no. 3	82	6.4
Louisiana no. 2	82	10.1
Tennessee no. 5	83	12.4
Tennessee no. 6	86	10.4
Louisiana no. 1	87	26.8
Colorado no. 1	87	15.6
Washington no. 2	88	7.8
South Carolina no. 1	90	19.8
Louisiana no. 4	91	9.5
Washington no. 1	94	8.1
California no. 2	95	8.5
California no. 4	96	5.4
Washington no. 4	97	4.1

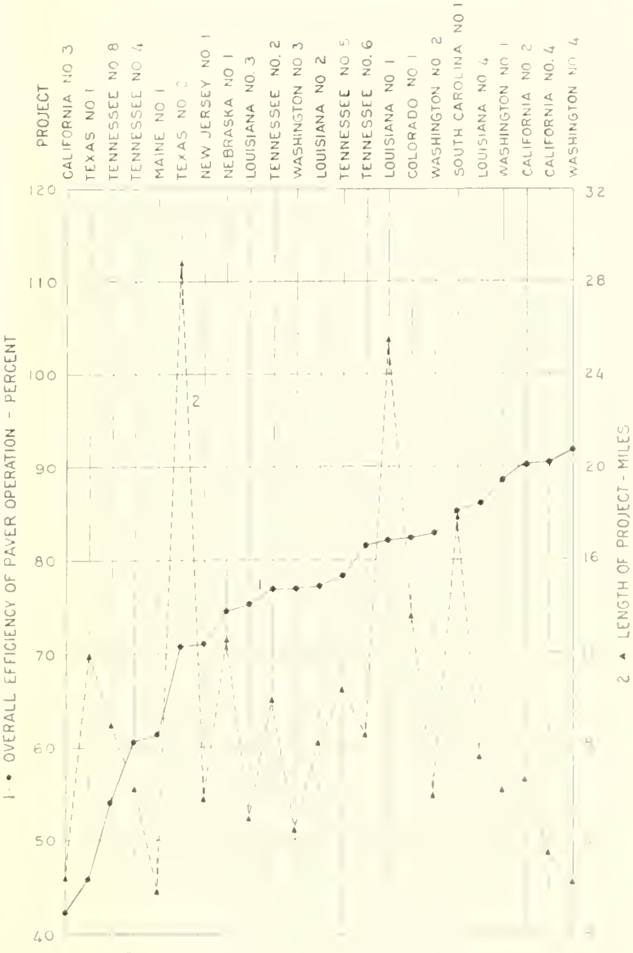
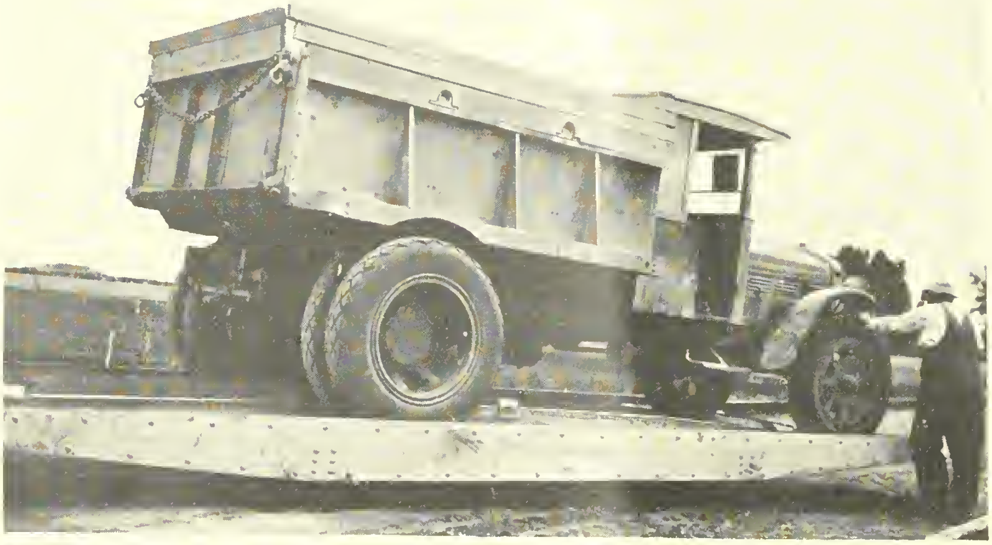
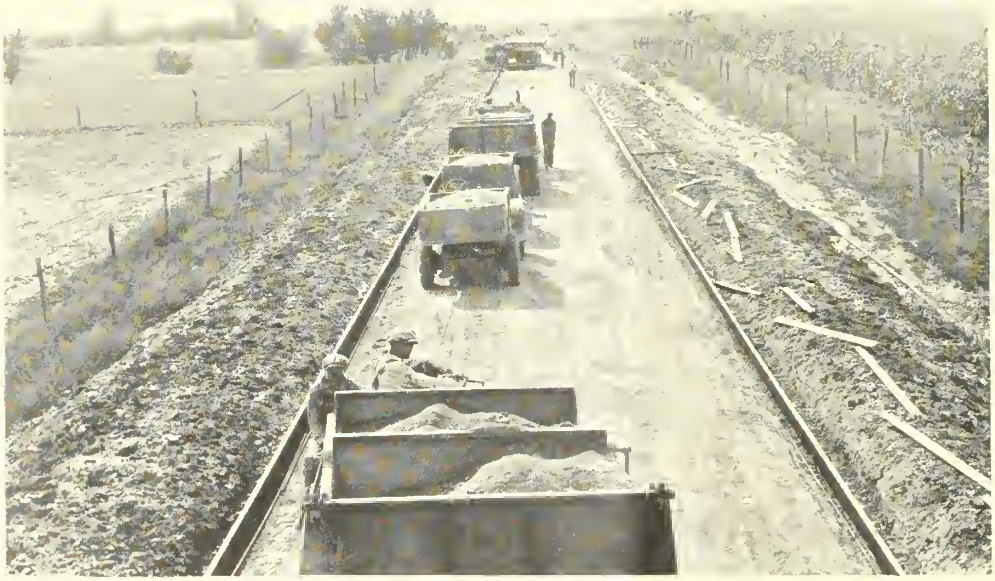


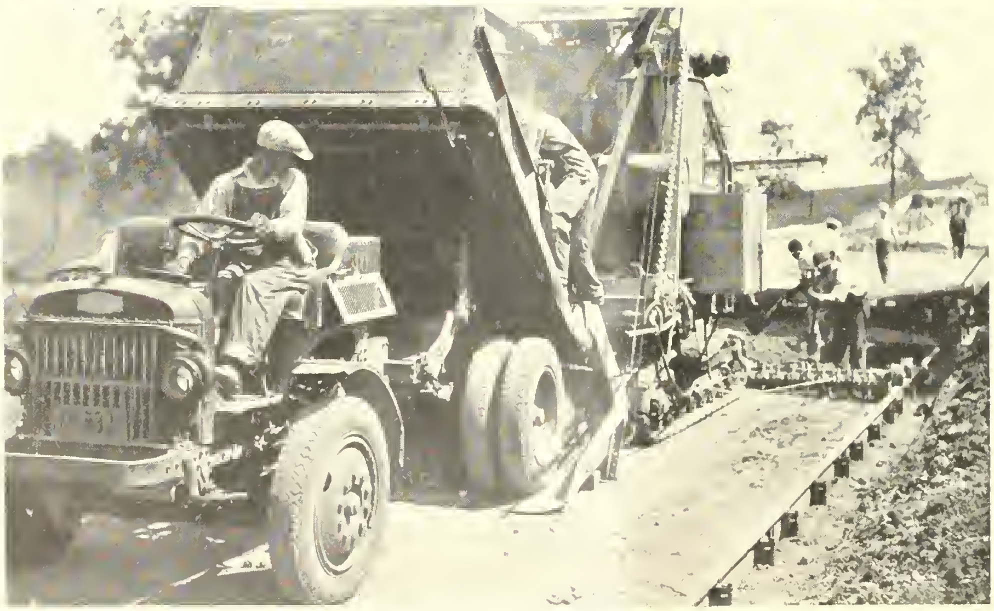
Figure 3.—Comparison of Efficiency and Length of Project.



Turntable for Trucks.



Trucks Ready to Back to Paver.



Dumping into Skip of Paver.

MINOR DELAYS RESULT FROM NUMEROUS CAUSES

Table 10 is a typical weekly summary of time losses and their effect on production. It shows the total available working time for the week, the time lost through avoidable and unavoidable major and minor delays, the production obtained, and the over-all efficiency of operation of major equipment.

Table 11 is a summary of weekly summaries covering the production studies on 23 projects using a single 27-E paver each and on 4 projects using two 27-E pavers each. The over-all efficiency of paving outfits ranges from 47.4 percent to 96.8 percent. Of the 10,651 hours that were available for paving on projects using a single paver, the paver operated at full efficiency only 4,973 hours, or 47 percent of the total available working time. Had the class B delays, those which could be eliminated under proper management, been eliminated, full production could have been maintained for 6,366 hours. The over-all efficiency of these 23 paving outfits representing nearly every section of the United States is 78 percent. The causes for the major delays and the time losses resulting from them are shown in table 12. The causes for the minor delays are shown in table 13. The results of these studies are believed to be a fairly accurate estimate of the efficiency with which major concrete paving equipment is operated in the United States.

Table 11 shows considerable difference in the over-all efficiency with which different contractors operated the major equipment. Table 1 indicates that the major and auxiliary equipment was about the same on all projects. Concrete paving equipment is fairly well standardized and in most cases the auxiliary equipment has a capacity corresponding to maximum paver production.

TABLE 10.—*Typical weekly summary of time losses and their effect on production*

[Project, Maine No. 1; equipment, one 27-E mixer, batcher, trucks, finishing machine; available working hours, 57.17; estimated production, 1,640 batches, or 6,560 lineal feet]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Source of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Hauling equipment supply			0.40	0.7		
Water supply			.25	.4		
Hose line			.28	.5		
Placing special steel	0.54	0.9				
Mechanical trouble at plant	1.24	2.2				
Waiting for finishers	2.95	5.2				
Total	4.73	8.3	.93	1.6	5.66	9.9

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

Source of delay	Class A		Class B		Total minor delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Hauling equipment operation			4.18	8.1		
Operator			1.10	2.1		
Handling cement			.63	1.2		
Placing steel			2.74	5.3		
Wet aggregate sticking in trucks			2.15	4.2		
Shifting hose and pipe line trouble			1.95	3.8		
Water supply			.38	.7		
Trouble at plant	0.29	0.4	.82	1.6		
Hauling equipment supply			.19	.4		
Mixer, mechanical	.14	.3				
Lack of subgrade and waiting for finishers	1.82	3.5				
Total	2.16	4.2	14.17	27.5	16.33	31.7

Major equipment operated 51.51 hours or 90.1 percent of available time.

Major equipment operated at 100 percent efficiency 35.18 hours or 68.3 percent of operating time. Possible operating time with all class B losses eliminated 50.28 hours. With all class B losses eliminated production would have been 2,344 batches. Over-all efficiency of operation of major equipment, 70 percent.

TABLE 11.—*Summary of time losses and efficiency of operation of major equipment*

PROJECTS USING A SINGLE 27-E PAVER

	Total available working time	Major delays as percentages of total available working time		Percentage of total available working time that major equipment actually operated	Minor delays as percentage of the time that major equipment actually operated		Percentage of actual operating time that major equipment operated at full efficiency	Time major equipment operated at full efficiency	Possible operating time, all class B delays eliminated	Over-all efficiency of major equipment operation
		Class A[1]	Class B[2]		Class A[1]	Class B[2]				
	Hours							Hours	Hours	Pct
California no. 2	456.0	32.1	0.5	67.4	1.1	3.9	95.0	292.0	306.2	95
California no. 3	168.0	9.5	41.9	48.6	5.1	9.0	85.9	70.1	117.8	47
California no. 4	370.7	12.9	0.0	87.1	3.4	4.3	92.3	298.1	312.0	96
Colorado no. 1	417.0	9.9	1.8	88.3	4.9	10.2	84.9	312.5	357.5	87
Louisiana no. 1	336.0	66.2	0.3	33.5	4.4	11.3	84.3	95.3	109.1	87
Louisiana no. 2	448.0	64.9	0.5	34.6	8.0	15.3	76.7	118.4	144.2	82
Louisiana no. 3	541.6	43.6	2.0	54.4	7.2	15.2	77.6	229.7	285.3	80
Louisiana no. 4	240.4	31.3	1.3	67.5	5.6	6.7	87.7	142.1	156.1	91
Maine no. 1	225.0	31.3	3.0	65.7	5.7	28.6	65.8	97.3	146.5	66
New Jersey no. 1	889.7	47.8	5.5	46.7	5.2	13.7	81.1	338.0	444.4	76
Tennessee no. 2	517.6	23.6	1.3	75.1	15.3	14.1	70.6	274.6	336.0	82
Tennessee no. 4	672.0	39.4	7.9	52.7	2.9	23.6	73.5	260.4	397.0	66
Tennessee no. 5	475.0	17.9	2.0	80.1	2.2	14.5	83.3	316.9	381.7	83
Tennessee no. 6	413.4	50.7	0.5	51.3	6.4	14.9	78.7	158.5	190.7	83
Tennessee no. 8	293.0	28.1	12.6	59.3	8.0	25.1	66.9	116.2	196.6	59
Texas no. 1	1,055.4	51.8	7.6	40.6	0.0	39.5	60.5	258.9	508.0	51
Texas no. 2	1,431.6	48.5	2.9	48.6	8.7	17.6	73.7	512.2	676.6	76
Washington no. 1	117.0	2.9	2.0	95.1	4.7	4.3	91.0	101.1	108.3	94
Washington no. 2	185.7	12.5	4.6	82.8	1.0	7.3	91.7	141.4	160.9	88
Washington no. 3	89.0	0.0	8.2	91.8	0.0	10.9	89.1	72.9	89.0	82
Washington no. 4	99.5	3.7	0.6	95.7	2.4	2.5	95.1	90.5	93.5	97
Nebraska no. 1	812.6	24.4	4.9	70.6	3.2	14.2	82.6	475.0	595.7	80
South Carolina no. 1	394.1	42.0	0.5	57.5	2.6	8.7	88.7	201.2	222.9	90
Total	10,651.3	37.3	4.2	58.5	5.0	15.2	79.8	4,973.3	6,366.0	78

PROJECTS USING 2 27-E PAVERS

	Total available working time	Major delays: Class A[1]	Major delays: Class B[2]	Percentage of total available working time that major equipment actually operated	Minor delays: Class A[1]	Minor delays: Class B[2]	Percentage of actual operating time that major equipment operated at full efficiency	Time major equipment operated at full efficiency	Possible operating time, all class B delays eliminated	Over-all efficiency of major equipment operation
California no. 5[3]	191.6	16.1	3.6	80.3	1.1	2.8	96.1	147.8	159.1	93
California no. 5[3]	191.7	15.3	3.3	81.5	1.7	3.9	94.4	147.4	159.8	92
Missouri no. 2[4]	305.4	45.5	3.4	51.1	3.8	17.7	78.5	122.9	160.6	76
Ohio no. 2[4]	321.7	40.9	9.6	49.5	4.9	21.1	74.0	117.8	182.0	65
Illinois no. 1[5]	211.4	26.3	3.8	69.9	16.3	5.7	78.1	115.4	131.9	88
Total	1,221.8	31.4	5.1	63.5	5.4	10.4	84.2	651.3	793.4	82

[1] Unavoidable.

[2] Avoidable.

[3] One of two pavers operating side by side.

[4] Two pavers side by side.

[5] Two pavers, one behind the other. Material is delivered to first paver and mixed for part of required time and then fed to second paver for completion of mixing

TABLE 12.—*Distribution of the major delays on 23 paving projects having a total available working time of 10,651 hours; the percentages are based on the total available working time*

Cause of delay	Major delays			
	Class A		Class B	
	Hours	Percent	Hours	Percent
Rain	1,290.0	12.1		
Wet subgrade	1,006.8	9.4		
Cold weather or snow	482.8	4.6		
Moving outfit	421.1	4.0		
Lack of prepared subgrade	240.4	2.3	128.5	1.2
Lack of materials	152.7	1.1	76.4	.7
Mixer trouble, mechanical	106.3	1.0	11.7	.1
Inadequate water supply	46.4	.1	21.7	.2
Stopping work early before regular stopping time	36.9	.1		
Finishing machine trouble, mechanical	21.0	.2		
Hauling equipment, operation			14.7	.1
Hauling equipment, shortage			30.3	.3
Miscellaneous	168.9	1.5	159.5	1.5
Total	3,973.3	37.3	442.8	4.2

Total major delays, 4,416.1 hours or 41.5 percent

Time major equipment actually operated, 6,235.2 hours or 58.5 percent

Table 13.—*Distribution of minor delays on the 23 paving projects during the 6,235 hours that the major equipment was operating; the percentages shown are based on the actual operating time*

Cause of delay	Minor delays			
	Class A		Class B	
	Hours	Percent	Hours	Percent
Wet subgrade	16.0	0.3		
Lack of prepared subgrade	12.8	.2	95.2	1.5
Hauling equipment, operation	17.1	.3	191.6	3.1
Hauling equipment, shortage	72.1	1.2	282.5	4.5
Inadequate water supply	27.4	.4	48.3	.8
Mixer trouble, mechanical	71.8	1.1	20.0	.3
Mixer trouble, operative			94.6	1.5
Moving mixer	9.2	.1		
Waiting on finishing operation			13.2	.2
Handling cement			15.3	.2
Placing joints and reinforcing steel			46.6	.8
Shifting hose at mixer			15.9	.3
Miscellaneous	85.6	1.4	126.7	2.0
Total	312.0	5.0	949.9	15.2

Total minor delays, 1,261.9 hours or 20.2 percent.
Time major equipment operated at full efficiency, 4,973.3 hours or 79.8 percent

Table 14 is a summary of time losses on a project having a high type of supervision and correspondingly efficient operation. On this project work was carried on during the winter months under unfavorable weather conditions, but even with this handicap a high rate of production was maintained during periods in which it was possible to work.

Table 15 shows the results of a study made on a project with inadequate supervision and a resulting low efficiency. Avoidable delays were forestalled on the first job, but were allowed to happen and to reduce efficiency on the second project.

Table 14.—*Summary of time losses on an efficiently managed project during entire period of study*

[Project, South Carolina no. 1; available working time, 394.1 hours; estimated production, 6,898 batches or 39,461 square yards]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Wet subgrade	59.88	15.20				
Rain	52.75	13.40				
Cold weather	51.53	13.10				
Mixer trouble, mechanical	.50	.14				
Water supply	.25	.06	0.28	0.07		
Truck operation	.50	.14	1.54	.39		
Totals	165.41	42.04	1.82	.46	167.23	42.50

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

Cause of delay	Class A		Class B		Total	
Shortage of hauling units	1.62	0.71	0.97	0.43		
Hauling units, operation	1.26	.56	8.67	3.81		
Mixer operator			7.08	3.11		
Subgrade			2.20	.97		
Mixer, mechanical	1.25	.55				
Setting joints			.18	.08		
Water supply	.75	.33	.59	.26		
Miscellaneous	.96	.42	.21	.09		
Totals	5.84	2.57	19.90	8.75	25.74	11.32

Major equipment operated 226.9 hours or 57.5 percent of available time

Major equipment operated at 100 percent efficiency 201 hours or 88.7 percent of operating time. Possible operating time with all class B losses eliminated, 222.9 hours. With all class B losses eliminated production would have been 7,643 batches. Over-all efficiency of operation of major equipment 90.3 percent.

Table 15.—*Summary of time losses on an inefficiently managed project during entire period of study*

[Project, Texas no. 1; available working time, 1,055.3 hours; estimated production 12,352 batches or 77,831 square yards]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Rain and wet subgrade	295.07	27.9				
Cold weather	212.12	20.1				
Moving	23.50	2.2				
Mixer, mechanical	16.67	1.6				
Lack of subgrade			13.26	1.3		
Lack of materials			12.00	1.1		
Water supply			11.42	1.1		
Truck supply			5.08	.5		
Truck operation			.63	.1		
Miscellaneous			37.71	3.5		
Totals	547.36	51.8	80.10	7.6	627.46	59.4

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

[No class A minor delays]

Cause of delay	Class B	
	Hours	Percent
Truck supply	38.1	8.9
Truck operation	41.6	9.7
Truck turning and backing operation	8.5	2.0
Mixer, mechanical	6.0	1.4
Mixer, operative	5.1	1.2
Water supply	8.5	2.0
Lack of subgrade	24.8	5.8
Finishing	8.1	1.9
Expansion joints	6.0	1.4
Miscellaneous	13.3	3.1
Charge and discharge mixer, mechanical	9.0	2.1
Totals	169.0	39.5

Major equipment operated 427.9 hours or 40.6 percent of available time.

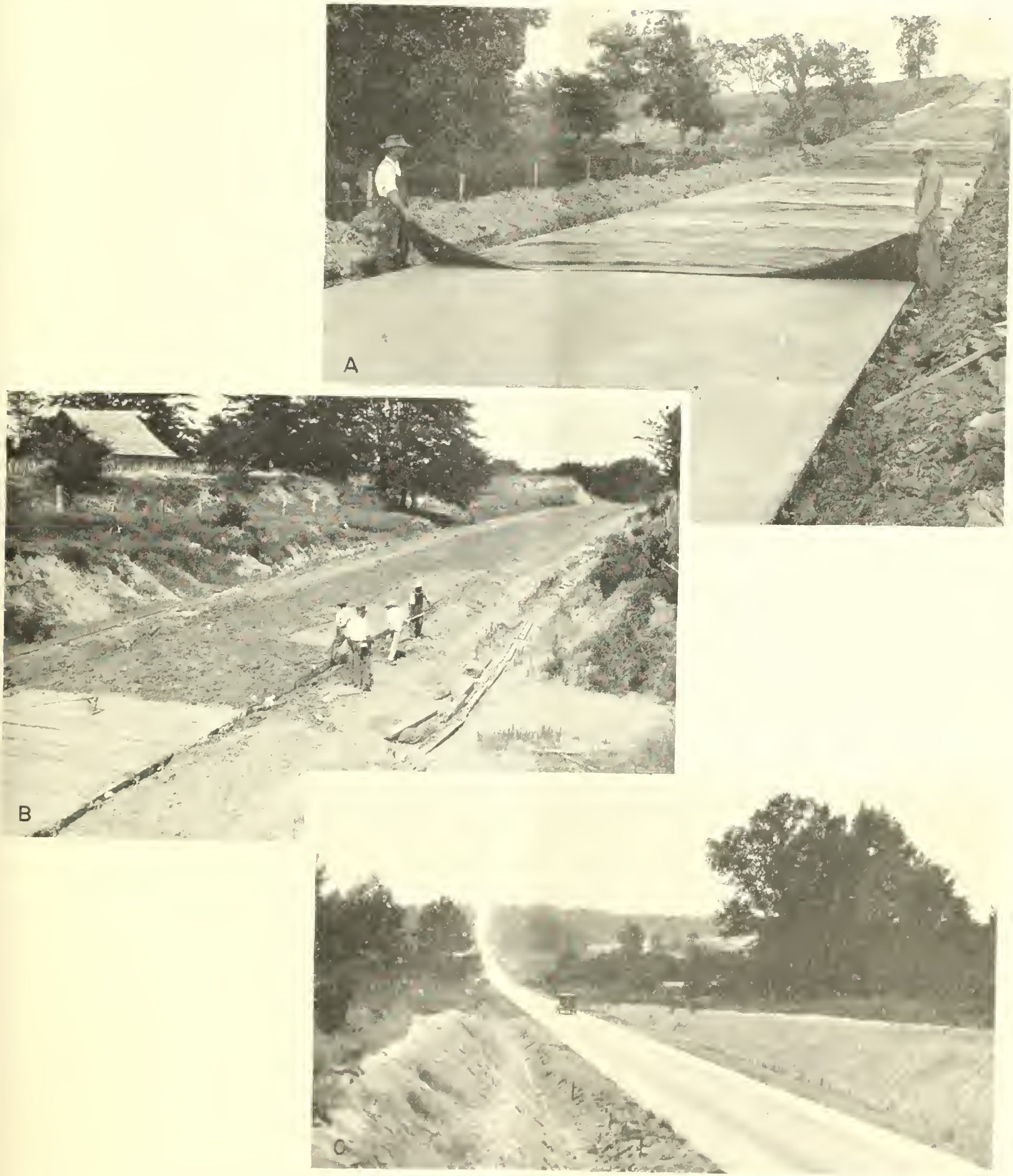
Major equipment operated at 100 percent efficiency 259 hours or 60.5 percent of operating time. Possible operating time with all class B losses eliminated, 508 hours. With all class B losses eliminated production would have been 24,238 batches. Over-all efficiency of operation of major equipment 50.9 percent.

CAUSES OF INEFFICIENCY DISCUSSED

Constant and proper supervision is the key to efficient operation. The type of supervision on nearly every project listed in table 11 is indicated with fair accuracy by the figure for over-all efficiency of operation of major equipment. A superintendent who understands highway construction, who realizes the importance of utilizing available working time to the fullest extent, and who has the ability to foresee and to prevent delays, is highly valuable.

It is evident that adequate supervision has not always been employed. The first reason that comes to mind is that contracting firms, in general, have not always realized the value of adequate supervision of construction. Administrative officers devote a major portion of their time to obtaining contracts and purchasing materials and partially neglect measures for attaining efficiency in construction. It has been customary to refer to highway construction as a "risky business", and there has been a tendency on the part of highway contractors to place much of the blame for inefficient operation on the element of risk rather than on a lack of proper supervision.

Another reason for low efficiency may be that there is no large supply of highway superintendents who have



A, covering concrete with burlap after finishing. *B*, placing earth covering after surface has hardened. *C*, the finished surface.

STEPS IN CURING.

a natural aptitude for the work, together with adequate experience in methods of construction and such special training in production work as enables them to appreciate the value of advance planning and of full use of available working time. Possibly the seasonal and intermittent character of concrete road construction has led qualified men to seek continuous employment in other lines of work.

Another factor affects the efficiency with which highway construction work is done. This can be termed "inspectional interference."

Inspectional interference is not to be confused with proper and adequate action in the enforcement of specifications. Proper inspection is a necessity. It is a factor which can be evaluated with reasonable accuracy in preparing bid prices. Inspectional interference, on the other hand, is the overstepping of the engineer's or inspector's authority to enforce specifications. Arbitrary requirements may be imposed on the contractor. An element of risk may be introduced which cannot usually be evaluated, but which must be considered in arriving at bid prices.

The reasons for such interference are natural ones. In some instances specifications do not state clearly what is desired. They may be contradictory also. Unnecessary interference has been found on many of the projects studied. The actual extent to which it has lowered operating efficiency is not shown in the results of the production studies. The lost time caused by such interference has been reported under the type of delay which it caused.

Unnecessary interference causes a loss of working time and also tends to discourage the employment of adequate supervision when the efforts and planning of a competent superintendent can be easily frustrated by a well-meaning but over conservative and autocratic resident engineer or inspector.

Many examples of unnecessary interference could be cited. Contractors are sometimes required to mix the concrete longer than the specified mixing time, because, in the inspector's opinion, it results in better concrete. It actually results, however, in decreased production and increased costs for labor and equipment. The hours of work are sometimes arbitrarily regulated. Instances have been observed where production has been stopped for extended periods in order that the templates and finishing-machine screeds might be checked although there was ample opportunity for checking during nonoperating time.

A rather absurd instance of interference was observed not long ago. Laborers emptying sacks of cement on trucks were required by the engineer to leap through the air from one truck to the next rather than to descend to the ground after the dumping operation. This was done to prevent the loss on the ground of cement adhering to the laborers' shoes. The laborers, after dumping cement on one truck could not start on the next truck until it came alongside so that they could jump to it. With two trucks abreast between the forms there was not sufficient room for the empty truck at the paver skip to proceed without delay. The empty truck had to wait its turn to pick its way between loaded trucks engaged in this maneuver. The hauling service was badly disrupted. Hauling costs were increased and paver production was decreased.

The daily operating cost for labor and equipment on a concrete paving project is approximately $580 as will be shown later. The cost varies but little whether the production per day is 250 or 500 cubic yards of concrete. The importance of efficient operation in reducing unit costs should not be overlooked. Neither should the fact be lost sight of that an efficient organization is in a much more favorable position to produce concrete of good and uniform quality than is the inefficient and intermittently operated outfit. Inspectional interference will be difficult to eliminate so long as both the results desired and the methods by which the contractor must obtain these results are specified, and so long as authority over the operation of the contractor's personnel and equipment, without responsibility for the finished product, is assumed by the inspector.

UNIT COSTS PER SQUARE YARD ANALYZED

State practices vary with regard to pavement thickness, cement factor, length of mixing time, size of batch, amount of reinforcing, and joint material used, etc., and it is difficult to calculate accurately the unit cost for concrete pavements for the country as a whole. During 1930, 10,600,000 square yards of plain cement concrete pavement were laid on Federal-aid projects at an average cost of $1.78 per square yard. Five and one-half million square yards of reinforced concrete pavement were laid on Federal-aid projects at an average cost of $2.16 per square yard. This gives a weighted average for all Federal-aid concrete pavements of approximately $1.90 per square yard. On the assumption that these unit prices are representative of prices for concrete pavements built by State and local authorities and that the proportions of plain and reinforced pavements for the total mileage built are about the same as for the Federal-aid mileage, the price of $1.90 per square yard will be used in the detailed analysis of costs.

The distribution of this unit cost in respect to the various items of expense is shown in table 16. The percentages have been calculated from data collected in cost studies. On individual projects, costs and their distribution will vary considerably from these figures, but the table is believed to be representative of average conditions.

TABLE 16.—*Distribution of average cost of cement concrete pavements on Federal-aid projects in 1930 of $1.90 per square yard* [1]

	Cost	Percent
Cement	$0.435	23
Transportation of cement [2]	.135	7
Total	.570	30
Coarse aggregate	.190	10
Transportation of coarse aggregate [2]	.190	10
Total	.380	20
Fine aggregate	.075	4
Transportation of fine aggregate [2]	.095	5
Total	.170	9
Cost and transportation of cement and aggregate	1.120	59
Reinforcing steel, joint material, etc	.115	6
Depreciation of equipment	.170	9
Labor and supervision	.210	11
Batch delivery (labor and equipment)	.135	7
Overhead, interest, bond, cost of set-up, etc	.075	4
Return to contractor, including salary	.075	4
Total	1.900	100

[1] Based on bid prices and includes cost of fine grading.
[2] Transportation to batching plant.

During 1930, approximately 10,000 miles of portland cement concrete pavements were built on rural highways. Assuming a pavement width of 20 feet, the cost per mile was approximately $22,500 and the total cost was $225,000,000. The percentage distribution of this total expenditure is shown in figure 4.

The analysis shows that the cost of cement and aggregates delivered to the contractor's plant is 59 percent of the pavement cost, and that 22 percent of this total pavement cost is for the transportation of materials from the source of supply to the batching plant on the project. Transportation charges constitute 37 percent of the cost of these materials.

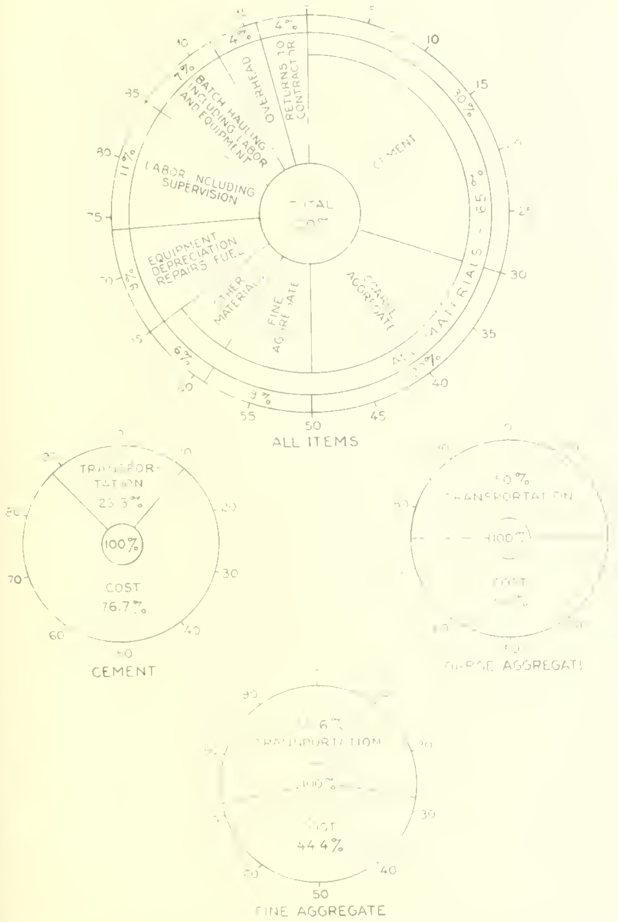


Figure 4.—Estimated Distribution of Expenditure on Portland Cement Concrete Pavements During 1930.

IF METHODS OF MIXING AND PLACING CAN BE IMPROVED, LESS CEMENT WILL BE REQUIRED

The largest item of expense is for cement the cost of which, delivered to the project, is about 30 percent of the total pavement cost. The cement factors used on the 34 projects studied during 1929 and 1930 varied from 1.23 to 2.10 barrels of cement per cubic yard of concrete. The possibility of reducing the amount of cement used without reducing the quality of the pavement is dependent on several factors, one of which is the uniformity with which the ingredients are distributed throughout the mass of concrete. Available information indicates that the present method of combining ingredients does not produce concrete in which these ingredients are uniformly distributed throughout the mass.

Analyses of samples removed from concrete after it has been spread on the subgrade show that variation in the amount of any one ingredient from one part of a batch to another part is often as high as 20 or 30 percent. One point in the batch may contain 10 or 15 percent more of an ingredient than the average for the batch while another point may be deficient by a similar amount. Percentage differences or "spreads" between points as high as 30 percent are not uncommon. The average spread in the proportion of any 1 of the 4 ingredients is about 10 percent. This lack of uniformity in the distribution of the ingredients no doubt accounts, to a large extent, for the wide variations that are found in the compressive strengths of cores removed from concrete pavements. Figure 5 shows the percentage spreads in materials on two different projects. These are typical examples of the lack of uniformity resulting from the present method of mixing concrete. Could the mixing be improved so that the ingredients would be uniformly distributed in the pavement, the cement content probably could be reduced, resulting both in a reduction in the cost of this material and a probable increase in the quality of the pavement.

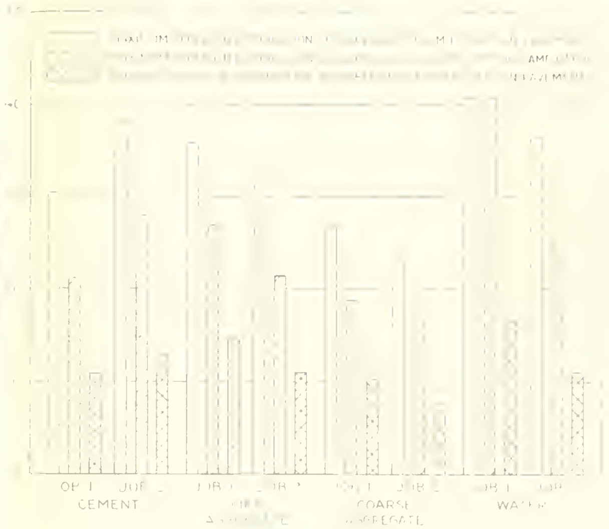


Figure 5.—Variation in Distribution of Ingredients of Concrete as Mixed in Standard Pavers.

Methods of manipulation must be considered in fixing the water and cement content of concrete. Present methods of placing concrete require rather wet mixes. It is generally accepted that the strength of concrete varies inversely with the ratio of the water to the cement. If methods of manipulation can be improved so that considerably drier concrete can be placed satisfactorily, a reduction in the amount of cement used should result.

The cost of reinforcing steel, material for joints, and other minor materials, averages 6 percent of the pavement cost. The cost varies considerably on different projects. Some States use heavy, double reinforcing while other States use no reinforcing. The spacing of transverse joints likewise varies between wide limits. Some States use no transverse joints while others space joints as close as 20 or 30 feet. For the 34 projects analyzed the transverse joints per square yard of pavement varied from none to 0.45 lineal foot.

EQUIPMENT COSTS ANALYZED

The cost of equipment is about 9 percent of the pavement cost. The most logical way to reduce this cost is to increase the efficiency with which equipment is operated by using a greater percentage of available working time. Annual or monthly expense for equipment is nearly constant except for field repairs, fuel, and lubricants. Costs do not vary materially with production obtained. The unit cost for depreciation, overhauling, major repairs, interest, taxes, storage, and insurance therefore varies almost inversely with the rate of production.

The unit cost for field repairs, fuel, and lubricants can be expected to vary nearly directly with the rate of production. There is no accurate method of determining equipment expense. The care that a piece of equipment receives is important in affecting its life. Equipment obsolescence affects costs. In the absence of a definite method of determining equipment expense, an approximation of the average daily equipment cost for the country as a whole is given in table 17. The figures shown in this table may not be applicable to every paving organization but they are suitable for use in general comparisons.

The figures in table 17 are based on an assumption that the average length of a construction season is 8 months (from Mar. 1 to Nov. 1). There are 245 days in this period of which 35 are Sundays and 3 are holidays. It is reasonable to assume that during an 8-month construction season the average paving contractor will have two projects. This necessitates a move from one project to the other. Allowing 12 working days for this move, 195 days or 24 days per month are available for operation. Table 12 shows that on the 34 projects analyzed the major unavoidable delays were as follows:

UNAVOIDABLE MAJOR DELAYS

Cause of delay:	*Percentage of available working time*
Rain	12. 1
Wet subgrade	9. 4
Cold weather, snow	4. 6
Moving equipment about project	4. 0
Lack of prepared subgrade	2. 3
Lack of materials	1. 4
Paver trouble, mechanical	1. 0
Inadequate water supply	. 4
Miscellaneous	2. 1
Total	37. 3

Thirty-seven percent of the total available working time was lost through delays of 15 minutes or over, delays that the contractor could not have been expected to anticipate and prevent. Delays from adverse weather conditions, wet subgrade, and moving the equipment about the project amount to 30 percent of available working time. Such delays generally last from one-half day to several days. During these periods the outfit usually does not operate, and the personnel, with the exception of straight-time men, is not on the job and does not draw pay.

The remaining delays, which amount to 7 percent of available working time, may or may not be of sufficient duration to shut down the outfit and stop production. In this discussion such delays will be considered as occurring during periods when the entire personnel is on the job and drawing pay. The possible

TABLE 17.—*Estimated equipment costs* [1]

Equipment	Number and capacity	Average annual expense as a percentage of first cost, exclusive of field repairs				Average use per year	Expense per working month	Application of schedule to specific prices		Estimated daily equipment cost for all items except field repairs, fuel, grease, and oil [2]	Estimated daily cost of fuel, oil, grease, and field repair	Total estimated daily equipment cost including all items
		Depreciation	Overhauling, major repairs, painting	Interest, taxes, storage, insurance	Total ownership expense			Price	Expense per working month			
		Percent	*Percent*	*Percent*	*Percent*	*Months*	*Percent*					
Fine grading:												
Blade graders	1, 10 foot	20	20	11	51	8	6. 4	$1, 250	$80	$4. 70	$0. 50	$5. 20
Tractors	1, 60 horsepower	20	15	11	46	8	5. 7	4, 300	245	14. 41	6. 90	21. 31
Scarifiers	1	25	20	11	56	8	7. 0	1, 000	70	4. 12		4. 12
Subgraders (form)	1	25	20	11	56	8	7. 0	1, 075	75	4. 41		4. 41
Subgrade planers	1	25	20	11	56	8	7. 0	500	35	2. 06		2. 06
Rollers	1, 6-ton	14	12	11	37	8	4. 6	2, 900	134	7. 88	3. 00	10. 88
Fresnos	2, 3-foot	33	20	11	64	8	8. 0	50	4	. 29		. 29
Fresno teams	2, 2-horse	10		6	16	12	1. 3	600	8	. 47	[3] 5. 30	5. 77
Handling and setting forms												
Forms	4,300 feet	25	20	11	56	8	7. 0	3, 440	241	14. 17		14. 17
Teams	1, 2-horse	10		6	16	12	1. 3	300	4	. 24	[3] 2. 65	2. 89
Form trenchers	1	25	20	11	56	8	7. 0	1, 800	126	7. 41	1. 50	8. 91
Handling materials:												
Crane (15-ton)	1, 1 cubic yard	17	10	11	38	8	4. 8	14, 000	672	39. 53	13. 50	53. 03
Batcher plant (complete)	1, 70 cubic yards	20	15	11	46	8	5. 7	2, 785	159	9. 34		9. 34
Cement house	1				75	8	9. 4	500	47	2. 76		2. 76
Pumps (water)	1	25	20	11	56	8	7. 0	1, 700	119	7. 00	3. 00	10. 00
Pipeline, 2½-inch	25,000 feet	25	5	11	41	8	5. 1	6, 425	328	19. 30		19. 30
Hose, 1½-inch	250 feet				50	8	6. 3	150	9	. 53		. 53
Truck (service)	1	36	14	11	61	8	7. 6	1, 150	88	5. 17	2. 50	7. 67
Hauling batches:												
Trucks [4]												
Turntable	1	25	15	11	51	8	6. 4	1, 000	64	3. 76		3. 76
Mixing: Paver, 27-E	1	25	15	11	51	8	6. 4	8, 800	564	33. 18	8. 50	41. 68
Finishing:												
Finishing machine	1	25	15	11	51	8	6. 4	3, 000	192	11. 29	2. 00	13. 29
Flaots	2				100	8	12. 5	50	6	. 35		. 35
Belts	2				100	8	12. 5	20	3	. 18		. 18
Bridges (wood)	4				100	8	12. 5	60	8	. 47		. 47
Curing:												
Burlap	1,300 lineal feet				100	8	12. 5	260	33	1. 94		1. 94
Hose, ¾-inch	400 feet				50	8	6. 3	40	3	. 18		. 18
Miscellaneous:												
Small tools					50	8	6. 2	500	31	1. 82		1. 82
Field machine shop tools					50	8	6. 2	500	31	1. 82		1. 82
Supervision: Automobile [5]	1	33	20	11	64	12	5. 3	1, 500	78	4. 59	3. 50	8. 09
Total								59, 655	3, 457	203. 37	52. 85	256. 22

[1] Cost of all items of expense except field repairs, fuel, oil, and grease based on modified Associated General Contractors' equipment ownership schedule.
[2] Based on 17 working days per month.
[3] Animal feed.
[4] Truck costs are variable depending on length of haul, and have been excluded from this analysis.
[5] Automobile used 26 days per month, but monthly cost charged to 17 productive days.

working time will therefore be 70 percent of 195 days, or 136.5 days. This gives 17 possible working days per month during a construction season.

Monthly equipment expense exclusive of field repairs, fuel, and lubricants is prorated over the 17 working days that equipment can be actually operated under average conditions. Daily costs for field repairs, fuel, and lubricants are based on observations made during the time studies and are estimates only. The total average daily equipment expense as derived by this method of estimating is $256. The portion of this expense regarded as constant regardless of production is $203.

The production studies show that the average contractor operates major equipment with an efficiency of 78 percent. With a 69-second mixing time and a batch of 27 cubic feet this means an average production of 300 cubic yards of concrete per 9-hour day, or a fixed unit cost for equipment of 85 cents per cubic yard. With an efficiency of 90 percent this fixed equipment charge would be 74 cents per cubic yard.

LABOR COSTS DISCUSSED

The cost of labor, including supervision, is 11 percent of the pavement cost. The number of men employed is usually that necessary to handle maximum paver production and remains relatively constant. It does not fluctuate as the hourly or daily rate of production fluctuates because of delays. The daily labor cost can therefore be considered as an almost constant amount. As production decreases, the unit cost for labor increases.

To determine daily labor cost it is first necessary to consider the basis of payment of personnel and that part of the personnel which is on the straight-time pay roll. Although there is some variation in the number of men carried on the straight-time pay roll by different paving organizations, the straight-time men are usually a superintendent, a timekeeper, four foremen, a crane operator, a paver operator, and a mechanic. Some common labor is also employed during periods of nonproduction and appears on the straight-time pay roll. However, such labor is affected by job conditions and therefore is omitted in this discussion. The superintendent is usually paid on a monthly or yearly basis. The other men on the straight-time pay roll are generally kept working on the job during periods of nonproduction and are usually paid on a weekly basis for all time except Sundays and possibly holidays. During an 8-month construction season the superintendent will usually be paid for 245 days. The remaining straight-time workmen will usually be paid for 245 days less 35 Sundays and 3 holidays, or 207 days. It is again assumed that there will be 136 productive days during the construction season on which the remaining personnel will be paid. Table 18 gives the approximate daily cost for labor per day of actual construction, assuming an average working day of 9 hours and wage rates which are averages for the country as a whole. Payments made to straight-time men are distributed among the productive days.

With an over-all efficiency of operation of major equipment of 78 percent and a daily pay-roll cost of $334.23, the unit labor cost is $1.11 per cubic yard. With an over-all efficiency of operation of 90 percent the unit cost would be 96 cents.

Table 18.—*Pay-roll costs on an assumed typical project for each productive day. Based on 136 productive days per season*

Position	Number	Daily rate	Days for which pay is received during season	Nonproductive days during season for which pay is received	Total cost of nonproductive time	Prorated cost of nonproductive time to each productive day	Daily cost of productive time	Total cost for each productive day
Superintendent	1	$12.00	245	109	$1,308	$9.62	$12.00	$21.62
Timekeeper	1	5.00	207	71	355	2.61	5.00	7.61
Foremen	4	6.00	207	71	1,704	12.53	24.00	36.53
Crane operator	1	9.00	207	71	639	4.69	9.00	13.69
Paver operator	1	7.00	207	71	497	3.65	7.00	10.65
Mechanic	1	6.00	207	71	426	3.13	6.00	9.13
Other machine operators	7	5.00	136	0	0	0	35.00	35.00
Semiskilled and heavy common labor	18	4.50	136	0	0	0	81.00	81.00
Ordinary common labor	34	3.50	136	0	0	0	119.00	119.00
Total	68				4,929	36.23	297.50	334.23

The cost for labor and equipment on concrete pavement construction during 1930 is estimated to have been $44,600,000. Had the general over-all efficiency of operation of major equipment been 90 percent instead of what it actually was it is reasonable to suppose that the total labor and equipment costs would have been reduced by at least $4,000,000. It is to the advantage of both contractors and engineers that concrete construction be carried on with a high degree of efficiency. Efficiency is advantageous to the contractor in his efforts to meet competition. A competent superintendent, invested with the necessary authority, is invaluable to him. Efficiency works to the advantage of the engineer as it is his duty to see that the general public receives the greatest value in both quality and quantity for expenditure for concrete pavements.

HAULING COSTS AN IMPORTANT ELEMENT

An estimate for the cost of equipment and personnel connected with batch hauling, that is, transporting the batches containing aggregates and cement from the batching plant to the paver, has not been included in the preceding analysis. The cost of batch hauling is estimated to be 7 percent of the pavement cost. This figure is based on average haul and costs on the projects studied. Transporting batches from the batching plant to the paver on the road is an operation separate from that of paving. It is synchronized with the paving operation in that a definite number of trucks is required to furnish the paver with the maximum number of batches that it can mix per hour. The hauling equipment on the average project is usually operated with less efficiency than is the major paving equipment. This is especially true where the hauling is sublet, in which cases the equipment is often owned and operated by several individuals and is not directly supervised.

The daily cost of truck operation is not affected by the amount of work done except in the items of field repairs, fuel, and lubricants. The cost for the truck driver will be the same regardless of the number of batches hauled. The daily cost of operating a hauling unit can be considered as almost a fixed charge. The unit cost of hauling batches will be determined by the number of batches that the truck can deliver per day, and this in turn will be determined by the following items:

1. Haul distance.
2. Condition of hauling road.
3. Efficiency of truck operation.
4. Number of trucks in excess of those required to match maximum paver production.
5. Efficiency of paver operation.
6. Length of time required for loading, turning, backing, passing through plant yard, dumping batch, waiting to dump first batch of multiple batch truck, time interval between the dumping of batches, and necessary delays.

Fluctuating production of the paver increases the unit hauling cost by causing delays to the hauling units. On the other hand an insufficient supply of hauling units or faulty operation causes delays to the paving organization. Table 13 shows that one-half of the minor avoidable delays to major equipment were due to these two causes and amount to 7.6 percent of the time that the major equipment was actually operating. Harmony between the paving operations and the hauling operations requires that the paving organization should operate at a uniform rate; that the hauling equipment be adequate for the rate of paver production; and that the hauling equipment be operated at a steady pace without interruption.

The investment in hauling equipment may be even greater than the combined investments in all the other equipment. Inefficient operation of hauling units may increase costs greatly.

The cost of overhead, interest, bonds, set-up charges, etc., is estimated at 4 percent of the bid price, and the return to the contractor in the form of salary and profit, after all other cost items have been met, is also placed at 4 percent. These items are more or less intangible and the percentages shown are merely estimates made for the purpose of this analysis. The true cost may be a few percent either way from the percentages shown, but the distribution of the remaining cost will not be materially changed from the figures shown in this cost analysis.

TABLE 19.—*Examples of job efficiency between 1923 and 1928*

Project no.	Year	Total available working time during study	Unavoidable delays	Avoidable delays	Time paver operated at full efficiency	Time paver could have operated at full efficiency had avoidable delays been eliminated	Actual efficiency of operation
		Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Percent*
1	1923	740.0	113.0	301.0	326.0	627.0	52.0
2	1924	222.0	63.8	71.2	87.0	158.2	55.0
3	1924	163.0	42.0	56.1	64.9	121.0	53.5
4	1924	146.0	36.5	40.0	69.5	109.5	63.5
5	1925	210.0	73.5	79.9	56.6	136.5	41.5
6	1925	477.5	157.8	120.2	199.5	319.7	62.5
7	1926	1,164.5	429.1	358.9	376.5	735.4	51.2
8	1927	1,143.3	197.3	465.1	480.9	946.0	50.9
9	1927	520.0	82.9	147.6	289.5	437.1	66.2
10	1928	512.0	90.0	182.3	239.7	422.0	56.8
Total		5,298.3	1,285.9	1,822.3	2,190.1	4,012.4	54.6

TABLE 20.—*Summary of weekly time losses on a project operated efficiently*

[Study made in 1931]

Week ending—	Batches produced	Total available working time	Major delays			Minor delays			Total of all delays
			Class A	Class B	Total	Class A	Class B	Total	
		Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
June 27	1,986	65.50	12.50	0.25	12.75	1.84	2.97	4.81	17.56
July 4	1,635	43.00	1.47	.25	1.72	.88	.89	1.77	3.49
July 11	1,447	65.35	29.21		29.21	.04	1.17	1.21	30.42
July 18	1,394	60.75	23.97		23.97	1.48	1.63	3.11	27.08
July 25	1,676	60.50	13.83	[1] 3.50	17.33	1.03	1.64	2.67	20.00
August 1	2,163	60.25	7.01	.25	7.26	.25	.34	.59	7.85
August 8	2,390	60.66	1.30	.75	2.05	.43	.40	.83	2.88
August 15	1,435	60.63	24.62		24.62	.89	.43	1.32	25.94
August 22	2,425	60.30	1.02		1.02	.30	.49	.79	1.81
Total	16,551	536.91	114.93	5.00	119.93	7.14	9.96	17.10	137.03

Week ending—	Time major equipment operated at 100 percent efficiency	Total of all class B delays	Possible operating time eliminating class B delays	Possible batches with class B delays eliminated	Over-all efficiency
	Hours	*Hours*	*Hours*		*Percent*
June 27	47.94	3.22	51.16	2,119	93.5
July 4	39.51	1.14	40.65	1,685	97.0
July 11	34.93	1.17	36.10	1,495	96.6
July 18	33.67	1.63	35.30	1,460	95.4
July 25	40.50	5.14	45.64	1,890	88.7
August 1	52.40	.59	52.99	2,190	98.9
August 8	57.78	1.15	58.93	2,438	98.1
August 15	34.69	.43	35.12	1,451	98.7
August 22	58.49	.49	58.98	2,445	99.2
Total	399.91	14.96	414.87	17,173	96.4

[1] Time required to remove hardened batch of concrete from drum

TABLE 21.—*Summary of time losses on project reported in table 20 and their effect on production*

[Total available working time, 536.9 hours. Estimated production, 16,551 batches]

TOTAL MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A		Class B	
	Hours	*Percent*	*Hours*	*Percent*
Rain	39.69	7.4		
Moving mixer	25.53	4.7		
Wet subgrade	18.74	3.5		
Pouring concrete gutter	12.75	2.4		
Mixer trouble, mechanical	8.56	1.6		
Pouring headwalls	5.89	1.1		
Removing concrete from drum			3.50	0.
Batcher trouble	1.55	.3		
Preparing subgrade			.75	.
Skip blocked by traffic	.62	.1		
Water supply trouble	.45	.1		
Truck operation	.40	.1		
Truck shortage	.25	.0		
Wreck	.25	.0		
Miscellaneous	.25	.1	.25	.
Late start			.50	.
Total	114.93	21.4	5.00	.

TOTAL MINOR DELAYS OCCURRING DURING TIME OF ACTUA OPERATION

Cause of delay	Class A		Class B	
	Hours	*Percent*	*Hours*	*Percent*
Truck operation	2.27	0.5	2.89	0.
Mixer trouble, mechanical	1.17	.3	2.15	.
Water supply	1.42	.3	.21	
Truck shortage	.30	.1	1.17	
Mixer operation			1.21	
Handling cement			1.05	
Placing reinforcing steel	.17	.0	.65	
Wet subgrade	.76	.2		
Rain	.58	.1		
Preparing subgrade			.35	
Miscellaneous	.12	.0	.15	
Setting expansion joint	.13	.0	.10	
Skip blocked by traffic	.11	.0		
Truck trouble, mechanical	.11	.1		
Dumping			.03	
Total	7.14	1.6	9.96	2

Total major delays 119.9 hours or 22.3 percent of working time.
Total minor delays 17.1 hours or 4 percent of working time.
Possible operating time with all avoidable delays eliminated 414.9 hours.
With all avoidable delays eliminated production would have been 17,170 batches
Over-all efficiency of operation of major equipment 96.4 percent.

EFFICIENCY IN CONSTRUCTION GREATLY IMPROVED IN RECENT YEARS

When production studies of highway construction were started in 1923 the efficiency with which concrete paving was laid was much less than it is today. Very little attention was given to attaining maximum paver production or to the full use of available working time. In recent years, there has been a gradual increase in the efficient use of working time. Table 19 indicates that trend.

The 10 projects listed in table 19 were studied in the years shown and are representative of supervision better than the average. With few exceptions the projects selected for efficiency studies were each several miles in length and all were constructed with standard paving equipment. The projects were located in five different States. Project no. 2 was in one of the central States. The contractor's organization on project 2 had the reputation of being the most efficient in the State, yet the major equipment was operated with an efficiency of only 55 percent.

In contrast with the rates of efficiency shown in table 19 for years prior to 1929, 10 of the projects studied in recent years (table 11), each using a single paver, were operated with an over-all efficiency of more than 85 percent and 6 projects were operated with an efficiency of 90 percent or more.

An example of the high efficiency that can be maintained in concrete paving is given in table 20. This is a summary of production studies made on a paving project in an eastern State during a period of 9 weeks in the summer of 1931. The drop in efficiency in the fifth week was caused by the paver operator's negligence in allowing a batch of concrete to harden in the mixer while the motor was being repaired. Table 21 contains a summary for the 9 weeks of operation and shows the cause and extent of all delays.

Efficient use of available working time has steadily increased. This increase has had a favorable effect on unit costs. It is generally recognized that this increase in the rate of production has had no adverse effect on the quality of pavements.

The cost of labor and equipment, however, is only a part of the cost of a concrete pavement. Improvements in the methods and equipment used in the production of paving materials as well as in the production of finished surfaces, together with more definite information concerning the design of concrete mixtures as developed through research will increase both the efficiency of concrete pavement construction and the value received by the public per dollar of pavement expenditure.

STATE GASOLINE TAXES, 1933

[Compiled for calendar year from reports and records of State authorities]

State	Gross tax assessed prior to deduction of refund	Exemption refund (deducted from gross tax)	Net tax earning on motor vehicle fuel [1] [2]	Other receipts, under tax law (licenses, etc.)	Grand total earning (tax and other receipts)	Disposition of grand total earning, according to law [2]						Tax rate, 1933			Gasoline, or other fuel for motor vehicles, taxed	
						Collection and administration cost [3]	Construction and maintenance on rural roads		State and county road bond payments [5]	On city streets	Other than highway purposes	Cents per gallon		Date of rate change	Net gallons taxes	Percent change [6]
							State highways [4]	Local roads [4]				Jan. 1	Dec. 31			
Alabama	$8,033,141		$8,033,141	$1	$8,033,142	$17,671	$2,508,119	$4,001,673	$1,505,679			6	6		133,885,679	−1.86
Arizona	3,226,831	$547,799	2,679,032	225	2,679,257	([7])	1,607,644	924,060			[8] $147,553	5	5	[9] Mar. 2	53,580,633	−7.63
Arkansas	6,543,025	553,596	5,989,429	8,861	5,998,290	220,147	1,376,222	639,566	[10] 3,446,153		[11] 316,202	6	[12] 6		114,791,930	33.35
California	38,774,555	3,557,393	35,217,162		35,217,162	[13] 82,134	22,817,380	12,036,373		$265,142	[14] 16,133	3	3		1,173,905,406	−2.52
Colorado	6,012,639	687,643	5,324,996		5,324,996	61,234	3,684,633	1,421,216		157,913		4	4		133,124,908	−2.64
Connecticut	4,962,513	150,883	4,811,630	45,394	4,857,024	([15])	4,857,024					2	2		240,581,476	2.71
Delaware	1,177,853	50,523	1,127,330	2,247	1,129,577	([16])	850,873		[17] 278,704			3	3		37,577,673	3.41
Florida	14,249,308		14,249,308	43,565	14,292,873	21,079	6,106,846		[18] 6,106,846		[19] 2,058,102	7	7		203,561,549	−1.79
Georgia	12,634,513		12,634,513		12,634,513	63,173	8,380,894	2,095,223			[20] 2,095,223	6	6		210,575,216	5.83
Idaho	2,535,966	253,596	2,282,370	796	2,283,166	11,868	2,055,048		[21] 216,250			5	5		45,647,396	0.20
Illinois	29,129,584	1,296,573	27,833,011		27,833,011	133,397	18,466,409	5,468,109			[22] 3,765,096	3	3		927,767,039	−3.20
Indiana	17,490,596	1,207,394	16,283,202	5,444	16,288,646	71,077	8,108,781	6,487,028		1,621,757		4	4		407,080,056	−2.73
Iowa	10,667,048	1,294,705	9,372,343		9,372,343	59,593	3,374,705	3,838,045	[23] 2,100,000			3	3		312,411,442	4.48
Kansas	10,258,397	2,526,578	7,731,819	39,550	7,771,369	[24] 179,454	5,779,180	1,800,000			[25] 12,735	3	3		257,727,287	4.20
Kentucky	8,314,659		8,314,659	1,358	8,316,017	48,246	8,267,771					5	5		166,293,182	1.36
Louisiana	8,155,482	46	8,155,436		8,155,436	62,000	2,361,222		4,100,825		[26] 1,631,389	5	[27] 5		163,138,863	−1.73
Maine	4,265,446	185,075	4,080,371	[28] 46,269	4,126,640	16,074	2,055,283	2,055,283				4	[29] 4		102,009,277	−3.00
Maryland	7,588,176	380,427	7,207,749		7,207,749	17,300	5,384,741	7,423		1,672,965	[30] 125,320	4	4		180,193,738	−3.90
Massachusetts	16,709,793	332,441	16,377,352		16,377,352	50,000	6,517,673	2,073,592	313,628		[31] 7,422,459	3	3		545,911,726	−0.86
Michigan	20,460,257	1,001,799	19,458,458	26,862	19,485,320	109,502	2,303,607	14,045,349	3,000,000		[32] 26,862	3	3		648,615,259	−4.76
Minnesota	11,326,991	1,312,134	10,014,857	[33] 198,779	10,213,636	([34])	6,425,314	3,600,000			[35] 188,322	3	3		333,828,560	0.14
Mississippi	6,721,859	920,134	5,801,725	[36] 299,223	6,100,948	23,311	2,874,459	2,573,341	495,192		[37] 134,645	6	6		96,695,407	−0.04
Missouri	9,317,610	236,475	9,081,135		9,081,135	55,934	9,025,201					2	2		454,056,751	1.47
Montana	3,415,209	663,906	2,751,303		2,751,303	31,512	2,650,591		69,200			5	5		55,026,065	2.27
Nebraska	7,792,812	86,551	7,706,261		7,706,261	56,411	5,095,848	2,298,602		255,400		4	4		192,656,526	−1.32
Nevada	825,176	129,523	695,653		695,653	([38])	695,653					4	4		17,391,339	−4.33
New Hampshire	2,418,103	68,254	2,349,849		2,349,849	([39])	1,762,387		587,462			4	4		58,746,216	−10.95
New Jersey	20,963,377	4,565,991	16,397,386	[40] 73,261	16,470,647	52,450	2,438,310	6,396,475	2,296,000		[41] 5,287,412	3	3		546,579,541	−1.32
New Mexico	2,430,319	164,809	2,265,510	16,382	2,281,892	33,935	898,005		1,349,952			5	5		45,310,187	3.34
New York	44,425,847	1,081,152	43,344,695	48,251	43,392,946	[42] 140,780	21,646,458	5,761,145		1,440,286	[43] 14,404,277	3	[44] 3		1,444,837,830	−2.71
North Carolina	14,974,123	204,521	14,769,602	3,680	14,773,282	6,099	4,952,913	2,931,286	[45] 6,540,385		[46] 342,599	6	6		246,160,036	6.23
North Dakota	2,787,728	863,777	1,923,951	879	1,924,830	25,000	1,266,553	633,277				3	3		64,131,714	4.81
Ohio	35,740,548	1,800,567	33,939,981		33,939,981	153,028	15,426,893	7,640,678		5,730,509	[47] 4,988,873	4	4		838,020,083	−2.18
Oklahoma	10,064,685		10,064,685	13,960	10,078,645	64,847	4,994,942	2,419,183			[48] 2,599,673	4	4		251,617,119	4.18
Oregon	7,282,245	938,354	6,343,891		6,343,891	20,616	4,604,599		[17] 1,718,676			4	5	June 9	135,819,611	−3.03
Pennsylvania	31,353,940	614,823	30,739,117	[49] 320,261	31,059,378	[50] 349,547	22,141,876	5,110,747	[17] 3,457,208			3	3		1,024,637,243	1.48
Rhode Island	2,004,038	123,066	1,880,972	3,710	1,884,682	([51])	1,246,567		302,000		[52] 336,115	2	2		94,048,613	1.45
South Carolina	6,716,510	37,184	6,679,326		6,679,326	([53])	1,924,367	1,113,221	[54] 3,641,738			6	6		111,322,101	7.30
South Dakota	3,849,544	[55] 503,529	[56] 3,346,015		3,346,015	41,399	1,900,047				[57] 1,404,569	4	4		78,382,211	5.80
Tennessee	12,979,882		12,979,882		12,979,882	154,721	3,481,115	[58] 3,847,548	[59] 5,496,498			7	7		185,426,887	6.52
Texas	31,430,379	2,951,029	28,479,350		28,479,350	201,122	14,139,114		[18] 7,069,557		[60] 7,069,557	4	4		711,983,752	5.23
Utah	2,189,065	67	2,188,998	716	2,189,714	4,241	2,185,473		([61])			4	4		54,724,960	0.79
Vermont	1,766,152		1,766,152		1,766,152		1,321,102	230,000	215,050			4	4		44,153,789	−5.79
Virginia	11,679,511	597,471	11,082,040		11,082,040	25,000	7,739,928	3,317,112				5	5		221,640,804	2.52
Washington	11,852,828	989,614	10,863,214		10,863,214	22,688	7,971,469	[62] 2,000,000			[63] 869,057	5	5		217,264,282	−1.66
West Virginia	5,149,595	229,931	4,919,664	8,064	4,927,728	11,506	1,759,477		3,156,745			4	4		122,991,600	−0.45
Wisconsin	16,599,578	1,430,152	15,169,426		15,169,426	29,705	9,255,610	[64] 3,992,249	[18] 1,284,000	107,862	[10] 500,000	4	4		379,235,644	1.48
Wyoming	1,405,415		1,405,415		1,405,415		829,042	351,354	[17] 225,019			4	4		35,135,367	0.90
District of Columbia	2,097,257	14,911	2,082,346		2,082,346					2,082,346		2	2		104,117,297	2.30
Total			518,195,712	1,207,738	519,403,450	2,727,801	277,517,371	111,109,158	58,972,767	13,334,180	55,742,173	Weighted average rate, 3.65 cents			14,224,321,270	−0.18

[1] Net gasoline tax earned after deduction of refunds allowed by law.

[2] Legislation enacted in several States authorizes the diversion of gasoline tax revenue to purposes other than for highways after such funds have been transferred by the collecting agency presumably for road purposes. In several such cases the reports of collecting agencies as given here indicate the initial distribution and not the final distribution. The County Commissioners of Florida counties of 4,135 to 4,300 population are authorized to transfer surplus money of road and bridge funds derived from the gasoline tax to courthouse and jail funds. Gilchrist County transferred $6,811. Legislation in Michigan provided possible contingent use of gasoline revenue for payment of calamity or welfare relief bonds. Allocations of gasoline tax funds to counties and cities in Ohio may be expended for poor relief.

[3] Many States pay collection cost from other State funds, and such are noted. Administration cost includes balances allocated to reserve funds for administrative purposes, and amounts are noted.

[4] Since this table covers the calendar year earnings, but not the actual collections during the year, these columns are not comparable with similar columns in tables F-1 and F-4 which cover different periods fixed by State and local agencies; also certain funds are allocated to bond payments shown in next column.

[5] For State highway bonds, except as noted.

[6] Shows percentage increase or decrease compared to net gallons reported in previous year.

[7] Approximately $16,000 paid from State highway budget.

[8] Relief fund, 1/10 of net motor fuel tax after June 30, 1933.

[9] On February 1 tax reverted to 4 cents and on date shown changed back to 5 cents.

[10] Includes $2,692,323 assignable to county bond payments.

[11] Transfer to State Charity fund.

[12] Tax rates of 2, 4, and 5 cents allowed at State borders.

[13] Consists of $61,099 to transportation division of State board of equalization and $21,035 to Controller refund division.

[14] Includes $14,297 for payment of claim and $1,836 for employees retirement fund.

[15] Cost of approximately $16,000 paid from motor vehicle license receipts.

[16] Paid from State general fund.

[17] Bond payments from combined fund of gasoline taxes and motor vehicle fees and pro-rated between them.

[18] Payments on county road bonds.

[19] To State general revenue fund.

[20] To an equalization fund for public schools.

[21] Payments on State highway treasury notes.

[22] Relief fund payments made from fund formerly apportioned to local roads.

[23] Payments on county bonds for State roads; obligations assumed by State.

[24] Law effective May 1, 1933 allowed 3 percent of net gasoline tax receipts for collection costs $7,500 from State general fund was used during first six months.

[25] To general funds (State, $1,607 and counties, $11,128).

[26] $815,694 for public schools, $815,695 for ports of New Orleans and Lake Charles harbor boards of commissioners.

[27] Rate of 4 cents permitted on 150,717 gallons near border.

[28] Includes receipts from 1 cent tax on gasoline not used in motor vehicles.

[29] Tax refund of 3 cents allowed for use other than in motor vehicles.

[30] $75,000 to conservation department; $48,000 for approaches to ferries, and $2,320 for protest fees

[31] To unemployment relief fund, and other nonhighway purposes

[32] For aeronautic fund $22,677 and $4,185 to State general fund.

[33] Includes inspection fees of 2 cents per 50 gallons.

[34] Paid by State appropriation of $13,000.

[35] Includes $172,909 cost of gasoline inspection and $15,413 to State General fund.

[36] Includes $121,342 from special tax in three counties for financing sea wall.

[37] $121,342 for sea wall, $11,600 for police patrol to enforce motor vehicle law, and $1,703 uncollected checks on closed banks.

[38] $7,500 paid from appropriation to State tax commission.

[39] $4,400 paid from motor vehicle license funds.

[40] Includes $4,802 from 2 cent tax on gasoline used by motor boats.

[41] $5,152,412 to State treasury and $135,000 to Department of Commerce and Navigation.

[42] Includes $50,000 paid to refund reserve.

[43] State general emergency fund from 1 cent extra tax.

[44] Tax rate of 2 cents allowed at border of State.

[45] Includes $360,319 for payments on county bonds.

[46] For police patrol and administration of motor vehicle laws.

[47] Consists of $2,000,000 for State emergency poor relief fund and $2,988,873 for public school fund.

[48] Consists of $2,262,625 for redemption of State warrants, $237,127 reserve for taxes paid under protest; $99,921 to State general revenue.

[49] Delinquent tax collections.

[50] Includes part of police patrol expenses; amount not reported.

[51] Paid from Motor vehicle fees, $15,558.

[52] To unemployment relief.

[53] Paid from State tax commission appropriation.

[54] Includes $2,712,661 for payments on county bonds

[55] New law effective during last nine months allows only 2 cent refunds

[56] This does not correspond to gallons taxed at 4 cent rate due to refunds being at 2 cent rate

[57] For payments on rural credit bonds

[58] Includes $183,217 allocated to roads in Great Smoky Mountain Park.

[59] Includes $1,832,166 payments on county bonds and same amount to sinking fund bonds

[60] For free school fund.

[61] Payments made from motor vehicle fees.

[62] Estimate based on previous year.

[63] Payments on State emergency relief bonds.

[64] Includes $1,133,818 allotted in lieu of personal property tax

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS 1 PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 4,185.067.00	$ 1.596.441.15	$ 880,571.63	$ 715.869.52	61.9	$ 4.625.778.67	$ 2,588.735.13	$ 2.037.043.54	44.5	272.3	$ 233.948.59	21.5	$ 481,811.65
Arizona	3.878.555.11	1.776.203.88	1,735.542.70		131.1	2,598.403.90	2.017.309.12		56.3	153.2	96,740.98	10.7	28.962.31
Arkansas	3.374.167.00	299.964.82	200.126.94	99.837.88	9.5	2.721.289.10	2,328.613.72	392.194.13	59.3	137.0	636.509.29	24.0	208.917.05
California	7,803.677.00	3.837.455.68	2,954.376.75		142.5	6.084,486.14	4.648.401.55		39.6	153.1	191.793.40	15.9	9.105.30
Colorado	3.437.265.00	1,514,031.69	1,500,790.30		96.0	2.059.925.09	1.926,296.72	27.435.65	54.1	54.9			10,177.98
Connecticut	1,404,213.00	31.798.76	31.798.76		.1	1.543.762.06	1,367.983.12	175.778.94	35.6	30.7			4.431.12
Delaware	909.544.00	192,063.14	191,170.71		3.0	698.741.30	698,741.30		63.8	14.7	5,770.00	.3	13.861.99
Florida	2.615.917.00	1.281.060.88	814,074.82	466,986.06	43.7	1.940.045.73	1.603.752.50	335.683.13	64.1	72.3	56.281.75	.7	141.807.93
Georgia	5.045.592.00	1.232.521.05	1,232,521.05		73.6	2.400.287.81	2,400.287.81		41.5	177.5	517.218.84	22.4	895,564.30
Idaho	2,166,858.00	824,604.86	809.780.19		81.8	1.281,245.97	1.239.392.09		47.9	93.5	13.782.82		103.902.90
Illinois	4,585.971.00	50.872.54	50.872.54		.9	2.712.498.06	2.712,498.06		43.1	45.1	1.762.692.49	13.3	59.907.91
Indiana	5.018,921.00					4,405,477.21	4,361.358.38		38.5	119.5	657.562.62	13.2	
Iowa	5.027.830.00	1.057.700.42	1.038.800.00		74.5	4.126.332.98	3.828.980.00		75.4	185.6	140.675.50	9.0	19.374.50
Kansas	5.044.802.00	1.330.234.56	1,329.365.58		206.5	3.917.385.48	3,690.045.12		78.4	191.1	25.391.30	.3	
Kentucky	3.608.332.00	554,103.01	549,646.72		59.6	2.599,204.31	2.590,365.88		69.3	177.9	468,319.40	16.5	
Louisiana	2.914.295.00	222,415.49	222,390.49		9.7	2.913.268.66	2.406,617.66		47.1	67.5	42,623.98	1.5	242,662.87
Maine	1,617,560.00					1.515.228.37	1,479,661.42		56.6	44.0	24.085.44	.2	113.813.14
Maryland	1,782,263.00					801.143.78	791,495.03		48.6	14.9	461,850.00	6.4	528,917.97
Massachusetts	1,101.716.00	289.573.84	212,377.94	69.984.24	6.4	1.123.369.76	807,710.12	315.659.64	64.6	31.4			81.627.94
Michigan	6.113.389.00	80.150.00	80,150.00		1.8	5.177.180.00	5.128,180.00	49,000.00	48.2	243.8	602.366.00	21.0	302,693.00
Minnesota	4,561.011.00	2.488,707.73	2,468,224.86	20.482.87	509.5	1.980,571.21	1.949.360.33	27,500.00	31.3	237.7	143.425.81	12.7	
Mississippi	3,489.337.00	288.524.53	164.210.19	124.314.34	12.8	4.586.982.35	2,481,349.56	2.067,000.85	48.0	235.2	276,070.22	29.1	567.707.03
Missouri	5.237,532.00	895.421.61	695,097.86		43.5	4.390,783.57	4.050,641.00	68.548.60	71.3	149.6	252.033.50	9.3	239.759.64
Montana	4.463,849.00	1.426.917.20	1.246,901.20	100.000.00	93.4	3.541.342.66	3.181.685.86	237,025.83	57.8	270.5	31,988.11	36.2	3.273.83
Nebraska	3,914,481.00	2.122.823.42	1.535.019.12	108,538.00	215.8	2.961.612.91	2.342.867.69		62.8	137.1	35.794.58	9.7	799.61
Nevada	2.909.387.00	1.349.395.18	1.349.395.18		173.0	1.401.020.43	1.401,020.43		31.8	87.1	79.129.02		79.842.37
New Hampshire	725.739.00	52,024.43	52.024.43		.3	601.203.04	594,695.63		81.6	10.5			79.018.94
New Jersey	3.099.370.48	66,077.87	66.077.87		6.1	2.756.285.14	2.601.364.13	139,466.42	32.4	36.4	63.503.88	.6	368.424.60
New Mexico	2.896,467.00	1.873.447.55	1.873.447.55		210.5	1.064.442.96	920,513.54	143.929.42	30.1	60.1	41.901.88	3.6	60.604.03
New York	10.271.846.00	510.222.64	410.162.64	43.000.00	8.0	11.280,608.68	9.660,723.68	315.000.00	54.3	230.0	146.997.80	8.4	53.961.88
North Carolina	4,761.147.00	1,037.299.11	714.521.55	322.777.56	103.5	3.310.836.86	2.957.506.09	353.330.77	45.6	465.1	493.815.98	52.9	595,303.38
North Dakota	2.902.224.00	1.050.552.17	1.047.220.19	3.294.32	457.9	1,513,926.68	1.315.248.81	198.677.87	47.0	404.6	473.289.70	138.2	66.465.30
Ohio	7.277.758.00	1.035.375.47	1.030,181.63		27.8	6.437.458.00	6.133.085.00	51.410.00	66.6	159.1	77.878.00	5.0	36.613.37
Oklahoma	4.608.399.00	1.239.211.18	1.237.607.64		101.4	2.931.335.69	2.931.335.69		77.0	196.3	146.968.44	3.1	292.487.23
Oregon	3.053.448.00	1.525.235.01	1.392.618.01	84,317.50	98.9	1.623.500.25	1.484.960.05	128.021.20	45.7	83.2	167.388.02	1.4	8.481.92
Pennsylvania	6,691.194.00	254.788.81	254.421.79		4.4	6.079.556.64	5,895.873.50		44.3	122.0	477.382.67	5.7	63.516.04
Rhode Island	999.354.00	50,178.00	50.178.00		1.1	937.119.34	937.119.34		68.2	19.4	8,732.36		3.324.30
South Carolina	2.729,583.00	263.440.39	263.440.39		24.3	2.039.404.99	2,036,675.37	2.729.62	50.7	186.3	144,097.11	9.0	285.370.13
South Dakota	3.005.739.00	1.086,296.08	1.066.954.69	19,341.39	184.9	1.849.893.45	1.542,099.63	307.793.82	24.1	250.2	143.477.48	41.9	253.207.20
Tennessee	4.246.309.00	1.393.206.06	1.180.143.76	213.062.30	61.5	2,914.317.84	2.553.157.65	361.160.19	54.3	104.0	390.724.63	24.2	122,282.96
Texas	12.122.012.00	4.182,635.90	3.504.691.72		542.4	7.415.941.62	6.877.286.38		44.3	457.5	328.563.97	26.2	1,411,469.93
Utah	2,374.205.00	1.432,093.17	1.429.324.46		146.0	798.151.16	798.151.16		59.5	48.8	68.204.10	.4	78.525.28
Vermont	928,184.00	90,524.22	89.926.93		7.4	847.698.77	818.249.22		59.0	37.4	3.998.46		16,009.39
Virginia	3.708,379.00	1.101.511.50	1,092.037.47	9.474.03	40.2	2.115.368.45	1.992.162.00	119.858.30	54.2	81.4	387,355.78	23.8	236.823.75
Washington	3.057,934.00	884,351.00	879,563.10	3.356.82	44.7	2.095.806.01	2.095,806.01		37.8	60.9	64.640.67	1.4	17.924.22
West Virginia	2.013.405.00	211.470.33	211.470.33		6.7	1.706.233.68	1,700.233.68		73.1	64.9	34.029.42	.7	67.671.57
Wisconsin	4.615.429.00	1.073.457.39	1.063,118.67	1.190.00	50.0	3.553.669.34	3,452.135.29	38.500.00	40.2	174.3	63.174.25	1.4	37.000.79
Wyoming	2.250.663.00	1.005.126.46	882,673.00	80,400.00	177.9	1.423.273.07	1,280.112.23	85,908.57	41.6	272.9	67.031.52	10.2	20,846.25
District of Columbia													
Hawaii	1.683.956.00	122,232.70	109.225.57	12.994.32	6.3	1,626.253.71	1.325.047.89	251.205.82	27.5	26.5	248.693.76	6.8	988.78
TOTALS	186.234.275.59	46.283,442.88	41.194,236.92	2.499.221.15	4.362.8	141.029.652.88	125.926.891.57	8,229,862.31	52.1	6.949.0	10.797.903.52	638.8	8.315.243.58

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOP NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$2.092.533.00	$183.974.41	$183.974.41		3.1	$1.133.335.74	$1.133.335.74		22.5	38.0	$703.763.64	18.4	$71.459.21
Arizona	807.982.36	179.423.43	177.982.55		4.0	300.059.89	300.059.89		33.0	7.3	284.883.32	2.0	45.056.60
Arkansas	1.889.534.00	267.409.01	239.810.94	$27.598.07	7.0	1.112.223.25	1.058.589.04	$53.384.21	39.2	28.4	487.403.12	5.8	103,730.90
California	4,213.986.00	1,201.380.99	1,077.458.87		13.8	2.800.607.08	2.505.943.04		23.9	35.6	586.972.69	3.6	43.611.40
Colorado	1.718.633.00	890,911.16	845.103.51		17.2	651.210.04	651.210.04		24.1	13.4	150.989.02	3.6	71.330.43
Connecticut	802,407.00	48.325.68	48.325.68		.5	687,857.65	684,715.77	3.141.88	83.9	9.2	68,293.81	.5	1,071.74
Delaware	454.772.00	82.851.95	75.106.31		.8	203.298.40	203.298.40		49.8	1.9	139.750.00	4.9	36.617.29
Florida	1.307.959.00	238.246.83	178.494.68	59.752.15	3.6	1.307.477.38	1.129.464.32	178.013.06	47.0	13.8			
Georgia	2.724.620.00	270.623.84	270,623.84		12.4	1,047,709.04	1.047.709.04		38.1	35.3	250.709.42	11.9	1.155.577.70
Idaho	1.197.829.00	191.286.86	187.894.42		4.8	965.953.20	943.374.52		26.5	13.5			66.560.06
Illinois	7.718.839.00	213.649.45	213.618.50		3.7	6.298,412.04	6.298.412.04		54.4	64.2	1,033.873.00	3.0	172.935.46
Indiana	4,416.651.00	49.616.53	49.616.53		1.2	2.548.474.57	2.548.474.57		16.7	49.5	1.419.950.27	19.3	398.609.63
Iowa	2.815.585.00	703,618.21	667.865.00		23.6	1.319.843.17	1.247.030.00		56.0	21.6	254.524.50	5.6	646.165.50
Kansas	2.522.401.00	727.167.34	723.495.87		18.5	1.930.602.57	1.785.748.77		75.6	18.7	13.156.36	.1	
Kentucky	2.029,687.00	128.112.17	128.112.17		3.2	731.168.11	724.814.00		40.8	17.3	460,899.41	9.6	715.861.42
Louisiana	1,457.148.00	329,889.35	329.889.35		6.5	617.871.43	617.871.43		24.9	17.8	509.387.22	2.8	
Maine	909.878.00	162.188.29	161.062.72		2.4	646.816.12	645.444.82		48.1	13.9	24.448.68	.4	78.921.78
Maryland	891.132.00					390.738.31	386.588.31		15.5	3.6			504.543.69
Massachusetts	5.007.199.00	96.850.68	73.850.68	23.000.00	1.8	4,475.346.95	4,436.270.79	39,076.16	31.3	13.7	250.293.28	1.0	246.784.25
Michigan	3.438.781.00	195.700.00	195.700.00		2.3	2.722.745.00	2.720.595.00		39.2	35.2	414,075.00	3.5	108,411.00
Minnesota	3.719.143.00	956.049.40	955.888.84		53.6	1.880.914.07	1.869.617.18	2.500.00	20.3	41.9	291.480.62	4.8	602.156.36
Mississippi	1.744.669.00	122.848.45	110.388.95	12.459.50	3.8	638.526.86	638.526.86		27.2	25.4	302.596.74	7.1	693.156.45
Missouri	4.019.501.00	559.179.26	533.233.11		12.7	2.946.033.18	2.542.530.91		44.9	38.8	329.298.82	6.0	614,438.16
Montana	1.115.962.00	345.305.18	345.305.18		9.2	585.139.71	585.139.71		8.2	17.0	178,482.37	9.1	7.034.74
Nebraska	1.957.240.00	269.117.63	268.428.34		11.7	1.569.767.55	1.569.767.55		63.2	20.1	98.955.75	1.5	20.088.36
Nevada	500.051.00	47.203.38	47.203.38		1.2	411.763.76	411.763.76		9.5	7.0			41.083.86
New Hampshire	706,640.00					678.365.95	664.365.95		70.3	15.6	42.274.05	.9	
New Jersey	3.190.118.00	94.073.38	94.073.38		2.1	2.846.861.99	2,792.728.99	30.000.00	43.5	19.9	41,442.01	.5	261,873.62
New Mexico	1.448,234.00	437.759.58	437.759.58		13.1	843.703.69	843.703.69		43.7	16.0	66,812.89	3.2	99.957.84
New York	8.449.487.00	259.723.17	259.341.87		4.0	8.006.217.60	7,489.785.00	39.000.00	47.3	57.7	32.800.00	.6	667.560.13
North Carolina	2,380.573.00	588.701.49	586.560.20	166.10	30.4	962.606.47	961.328.18		23.4	34.4	285.608.05	10.0	547,076.57
North Dakota	1.451,112.00	128,994.64	128.994.64		9.3	454,556.75	427.371.39	27.185.36	50.4	13.7	595.459.44	25.2	299.286.53
Ohio	4.335.686.00	495.616.80	455.579.08		9.4	4.109.684.43	3.625.318.43		60.2	47.2	248.288.37	2.7	6.500.12
Oklahoma	2.304.200.00	220.928.88	220.571.20		7.9	1.664.345.07	1.664.345.07		48.4	32.0	196.978.40	4.5	222.305.33
Oregon	1.526.724.00	422.188.01	406.695.04	14.126.97	9.8	874.529.63	863.369.98		28.2	14.6	145.261.52	3.3	111.397.46
Pennsylvania	4.854.988.00	778.975.47	761,814.18		16.9	2.963.101.24	2.905.023.58		48.0	35.8	598.476.07	6.2	589.674.17
Rhode Island	499.677.00	54.063.40	54.063.40		1.2	338.974.92	338.974.92		54.9	5.2	106.638.68	1.0	
South Carolina	1.364.791.00	147.768.44	147.768.44		4.1	725.672.31	725.267.30	405.01	31.6	30.2	251.062.11	7.8	240.693.15
South Dakota	1.502.870.00	183.149.74	183.149.74		8.1	680.060.88	680.060.88		34.9	21.9	280.530.04	9.0	359.129.34
Tennessee	2.123.155.00	307.829.45	307.829.45		6.7	1.140.039.95	1.140.039.95		44.6	14.3	415.580.58	4.8	259.704.72
Texas	6.061.006.00	1.605.904.15	1.523.073.09		56.4	3.146.496.84	3.079.890.27		22.0	49.4	609.566.77	9.0	848.475.87
Utah	771.826.00	619.358.49	603.798.90		13.9	54.015.64	53.422.98		35.8	2.8			114.604.12
Vermont	500.509.00	41.791.73	41.791.73		1.9	455.511.48	433.717.27	5.538.96	40.6	12.0	25.000.00	.7	
Virginia	2.008.458.00	402,536.67	381.276.18	8.760.49	10.9	1,330.699.04	1.142.139.89		33.5	12.1	338.503.96	5.0	146.537.97
Washington	1.977.260.00	1.187.895.49	1.173.567.02		20.7	786.454.90	786.454.90		22.0	11.7			17.235.08
West Virginia	1.342.270.00	87.291.15	87.291.15		1.9	950.313.53	925.967.79		48.2	16.2	187.844.31	2.2	141.166.75
Wisconsin	2.684.067.00	399.615.60	393.308.77		13.5	1.870.171.39	1.834.767.78	25.898.24	46.4	35.2	259.388.07	3.1	196.602.38
Wyoming	1.125.332.00	82.029.39	81.528.69		1.6	922.428.60	885.471.78		50.5	18.3	45.380.40	3.2	112.951.13
District of Columbia	959.235.00	289.445.89	289.445.89		2.4	680.633.97	663.650.15		64.0	2.3			6.138.96
Hawaii													
TOTALS	115.042.340.36	17.297.070.49	16.707.715.45	145.863.28	468.8	76.409.641.34	73.613.461.62	404.442.88	41.8	1,120.6	13.027.083.06	227.4	11.694.080.23

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2.092.533.00	$ 26.236.82	$ 26.236.82	.1	$ 857.518.34	$ 857.518.34	12.8	59.7	$ 960.759.52	83.0	$ 248.018.32	Alabama
Arizona	525,422.53	90.857.40	90.857.40	6.3	441.468.95	429,341.96	44.5	36.0			5,223.17	Arizona
Arkansas	1.484.634.00	41.727.43	41.727.43	15.9	948.842.90	948.842.90	34.9	118.9	135.002.66	9.3	359.061.01	Arkansas
California	3.589.691.00	617,476.51	497.034.19	16.0	3.204.357.74	2.721.574.10	33.7	154.9	151,579.17	6.7	219.503.54	California
Colorado	1.718.632.00	617.189.08	616.485.80	82.2	1.025.898.66	994.429.71	73.5	94.0	80.000.00	3.4	27.716.49	Colorado
Connecticut	659.120.00				664.915.58	659.120.00	27.8	14.5				Connecticut
Delaware	454.772.00				181.790.00	181,790.00	41.8	1.8	72.547.50	12.2	200.434.50	Delaware
Florida	1.307.958.00	397.589.88	397.589.88	26.0	850.256.61	850.256.61	65.9	45.6	28,423.34	3.6	31.688.17	Florida
Georgia	2.320.973.00	69.600.63	69,600.63	4.2	920.605.43	920.605.43	49.6	77.3	277,397.03	25.2	1.053,369.91	Georgia
Idaho	1.121,562.00	650.200.91	588.778.89	70.8	546.438.63	532.783.11	55.9	71.1				Idaho
Illinois	5.265.960.00	276.114.65	276.114.65	42.0	4.610,167.64	4,610,167.64	42.2	268.3	379,677.71	10.3		Illinois
Indiana	602,271.00				540,734.86	540.734.86	46.2	69.2			61,536.14	Indiana
Iowa	2,212,245.00	238.660.03	229,800.00	49.2	1.821.511.10	1.640,950.00	54.5	214.0	341.495.00	58.9		Iowa
Kansas	2.522.401.00	345.683.96	345.683.96	17.2	2.182.166.63	2.170.276.56	54.9	146.6	6,440.48	1.7		Kansas
Kentucky	1.879,340.00	448.942.86	448.876.03	69.0	1,391.976.64	1.390.591.40	66.0	146.5	30.000.00	5.4	9.872.57	Kentucky
Louisiana	1.457.148.00	73.405.37	73.405.37	2.4	922.070.51	922.070.51	24.9	42.9	286.879.00	11.5	174.793.12	Louisiana
Maine	842.479.00	577.668.36	571.325.97	54.5	347,893.22	261,598.53	95.0	27.4			9.554.50	Maine
Maryland	891.132.00	22.217.70	22.217.70	1.9	577.528.60	563.602.60	64.5	44.0	262.345.90	17.0	42.965.80	Maryland
Massachusetts	488.185.00				469.741.41	469.741.41	75.1	15.2			18.443.59	Massachusetts
Michigan	3.184,057.00	88,500.00	88.500.00	7.3	2,798.900.00	2.798.900.00	37.7	218.3	182.300.00	2.7	114,357.00	Michigan
Minnesota	2.376.415.00	573.461.23	561.616.55	81.8	1.619,796.48	1.613.476.33	46.4	190.1	5.000.00	1.5	196.322.12	Minnesota
Mississippi	1.744.669.00				801.275.41	801.275.41	42.6	92.4	445,874.39	40.0	497.519.20	Mississippi
Missouri	2.923.273.00	504,000.61	504,000.61	141.8	2.307.941.20	2.307.941.20	77.0	353.6	49.901.33	5.1	61.429.86	Missouri
Montana	1.859.937.00	712.695.05	712.695.05	97.6	1.119.834.58	1,119.834.58	20.5	125.0	26.572.33	3.5	835.04	Montana
Nebraska	1,957.240.00	213.260.07	213.260.07	70.3	1.834.682.07	1,728.953.58	64.8	213.3	12.325.86	.1	2.700.49	Nebraska
Nevada	1,136.479.00	700,561.17	700.561.17	70.6	307.468.71	307.468.71	38.1	28.2			128.449.12	Nevada
New Hampshire	477.460.00	82,647.15	82.647.15	2.5	435.560.52	394.736.67	76.5	23.2			76.18	New Hampshire
New Jersey	56,550.52				56.550.52	56.550.52	80.7	.5				New Jersey
New Mexico	1.448.234.00	351.481.58	351.481.58	62.1	874,633.59	874,633.59	58.3	240.3	20.000.00	3.0	202.118.83	New Mexico
New York	3.608.768.00	333.721.33	333.721.33	11.8	3,702.200.00	3,264.550.00	52.2	87.8			10.496.67	New York
North Carolina	2.380.573.00	690.265.25	689,866.92	51.2	1.119.390.77	1,081,106.83	36.1	126.2	80.200.00	15.1	529,399.25	North Carolina
North Dakota	1.451,112.00	6,021.51	6.021.51	1.4	176,701.59	176.701.59	33.3	22.5	545.234.59	165.0	723.154.31	North Dakota
Ohio	3.871,148.00	610.460.00	610.460.00	159.9	3,316.490.00	3.016.818.00	88.3	142.5	193.150.00	2.5	50.720.00	Ohio
Oklahoma	2.304,199.00	31.741.28	31.741.28	2.9	1.783.376.08	1.677,379.13	24.3	194.4	567.265.51	73.8	27.813.08	Oklahoma
Oregon	1.526.724.00	541.068.81	502.843.61	41.7	1.050.254.52	928.020.15	34.3	55.7	95.860.24	11.1		Oregon
Pennsylvania	7,344.822.00	258.906.83	258.906.83	30.0	6.821.281.19	6.735.617.79	49.7	605.3	252,768.17	20.7	97.529.21	Pennsylvania
Rhode Island	499.677.00				412,465.02	412.465.02	57.0	33.2			87.211.98	Rhode Island
South Carolina	1,364.791.00	54.313.20	54.313.20	1.6	1.247.341.80	1.247.341.80	54.9	144.0	63.136.00	8.7		South Carolina
South Dakota	1,502.870.00	183.741.74	183.741.74	73.2	427,523.09	427.523.09	36.2	140.4	410,634.58	153.1	480,970.59	South Dakota
Tennessee	2.123,155.00	342.701.04	342,701.04	29.3	955,167.96	955,167.96	54.0	74.3	636.341.23	48.8	188.944.77	Tennessee
Texas	6.061.006.00	2,385.381.53	1.835.753.10	408.9	3,984.158.53	3.667.285.48	48.4	366.8	117.416.66	2.5	440.550.76	Texas
Utah	1.048.677.00	523.984.51	504.437.24	107.3	470.666.59	445.300.00	55.7	51.3	68,967.69	5.9	29.972.07	Utah
Vermont	438.880.00				444,002.49	424.132.63	38.0	36.0	14,747.37	.4		Vermont
Virginia	1,699.920.00	518,382.22	498,897.89	96.9	1.054.220.53	993.814.18	54.4	108.5	160,251.99	1.0	46,955.94	Virginia
Washington	1.080.673.00	403,092.71	393,092.71	27.6	653.151.30	653,151.30	31.4	36.1	27.739.30	3.9	6,689.69	Washington
West Virginia	1.118.559.00	21,945.79	21.945.79	.7	897.576.45	897.576.45	42.0	50.0	127.232.93	9.2	71.803.83	West Virginia
Wisconsin	2.425,385.00	894.060.15	858.749.84	58.8	1.333.491.78	1.288.586.71	26.2	95.3	148,404.19	16.6	129.644.26	Wisconsin
Wyoming	1.125.332.00	465.442.38	454,233.00	56.6	626,347.56	611.181.00	45.2	91.6	59.918.00	9.6		Wyoming
District of Columbia	959.234.00	208.113.99	208.113.99	2.6	750,914.71	750,914.71	40.2	5.2			205.30	District of Columbia
Hawaii	187.106.00				177.717.69	177.717.69	32.0	4.9			9.388.31	Hawaii
TOTALS	92,723.384.05	16.193.522.72	15.300.037.92	2.154.1	66.066,966.15	63.502.117.77	49.2	5.604.8	7.323,789.67	852.0	6.597.438.69	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

o. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

o. 660D . . Highway Cost Keeping. 10 cents.

o. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

ECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

No. —— . . Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

No. 191 . . . Roadside Improvement. 10 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regiona Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF JUNE 30, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANC[illegible] PUBLIC [illegible] FUNDS AVAILABLE F[illegible] ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8.370.133	$ 1.806.652.38	$ 1.090.782.86	$ 715.869.52	65.1	$ 6.616.632.75	$ 4.579.589.21	$ 2.037.043.54	33.1	370.0	$ 1.898.471.75	122.9	$ 801.289.18
Arizona	5.211.960	2.046.484.71	2.004.382.65		141.4	3.339.932.74	2.746.710.97		51.9	196.5	381.624.30	12.7	79.242.08
Arkansas	6.748.335	609.101.26	481.665.31	127.435.95	32.4	4.782.355.25	4.336.045.66	445.578.34	49.0	284.3	1.258.915.07	39.1	671.708.96
California	15.607.354	5.656.013.18	4.528.869.81		172.3	12.089.450.96	9.875.918.69		34.0	343.6	930.345.26	26.2	272.220.24
Colorado	6.874.530	3.022.131.93	2.962.379.61		195.4	3.737.033.79	3.571.936.47	27.435.65	54.1	162.3	230.989.02	7.0	109.224.90
Connecticut	2.865.740	80.124.44	80.124.44		.6	2.896.535.29	2.711.818.89	178.920.82	45.9	54.4	68.293.81	.5	5.502.86
Delaware	1.819.088	274.915.09	266.277.02		3.8	1.083.829.70	1.083.829.70		57.5	18.4	218.067.50	17.4	250.913.78
Florida	5.231.834	1.916.897.59	1.390.159.38	526.738.21	73.3	4.097.779.72	3.583.473.43	513.696.19	59.1	131.7	84.705.09	4.3	173.496.10
Georgia	10.091.185	1.572.745.52	1.572.745.52		90.2	4.368.602.28	4.368.602.28		42.4	290.1	1.045.325.29	59.5	3.104.511.91
Idaho	4.486.249	1.666.092.63	1.586.453.50		157.4	2.793.637.80	2.715.549.72		42.0	178.1	13.782.82		170.462.96
Illinois	17.570.770	540.636.64	540.605.69		46.6	13.621.077.74	13.621.077.74		48.0	377.6	3.176.243.20	26.6	232.843.37
Indiana	10.037.843	49.616.53	49.616.53		1.2	7.494.686.64	7.450.567.81		31.6	238.2	2.077.512.89	32.5	460.145.77
Iowa	10.055.660	1.999.978.66	1.936.465.00		147.3	7.267.687.25	6.716.960.00		66.7	421.2	736.695.00	73.5	665.540.00
Kansas	10.089.604	2.403.085.86	2.398.545.41		242.2	8.030.154.68	7.646.070.45		71.1	356.4	44.988.14	2.1	
Kentucky	7.517.359	1.131.158.04	1.126.634.92		131.8	4.722.349.06	4.705.771.28		63.9	341.7	959.218.81	31.5	725.733.99
Louisiana	5.828.591	625.710.21	625.685.21		18.6	4.453.210.60	3.946.559.60		38.5	128.2	838.890.20	15.8	417.455.99
Maine	3.369.917	739.856.65	732.388.69		56.9	2.509.937.71	2.386.704.77		58.5	85.3	48.534.12	.6	202.289.42
Maryland	3.564.527	22.217.70	22.217.70		1.9	1.769.410.69	1.741.685.94		46.4	62.5	724.195.90	23.4	1.076.427.46
Massachusetts	6.597.100	386.424.52	286.228.62	92.984.24	8.2	6.068.458.12	5.713.722.32	354.735.80	39.6	60.3	250.293.28	1.0	346.855.78
Michigan	12.736.227	364.350.00	364.350.00		11.4	10.698.825.00	10.647.675.00	49.000.00	43.1	497.3	1.198.741.00	27.2	525.461.00
Minnesota	10.656.569	4.018.218.36	3.985.730.25	20.482.87	644.9	5.481.281.76	5.432.453.84	30.000.00	32.0	469.7	439.906.43	19.0	798.478.48
Mississippi	6.978.675	411.372.98	274.599.14	136.773.84	16.6	6.026.784.62	3.921.151.83	2.067.000.85	43.5	353.0	1.024.541.35	76.2	1.758.382.68
Missouri	12.180.306	1.958.601.48	1.732.331.58		198.0	9.644.757.95	8.901.113.11	68.548.60	65.2	542.0	631.233.65	20.4	915.627.66
Montana	7.439.748	2.484.917.43	2.304.901.43	100.000.00	200.2	5.246.316.95	4.886.660.15	237.025.83	43.3	412.5	237.042.31	48.8	11.143.61
Nebraska	7.828.961	2.605.201.12	2.016.707.53	108.538.00	297.8	6.366.062.53	5.641.588.82		63.5	370.5	147.076.19	11.3	23.588.46
Nevada	4.545.917	2.097.159.73	2.097.159.73		244.8	2.120.252.90	2.120.252.90		28.4	122.3	79.129.02		249.375.35
New Hampshire	1.909.839	134.671.58	134.671.58		2.8	1.715.129.51	1.653.798.25		75.8	49.3	42.274.05	.9	79.095.12
New Jersey	6.346.039	160.151.25	160.151.25		8.2	5.659.697.65	5.450.643.64	169.466.42	38.6	56.9	104.945.89	1.1	630.298.22
New Mexico	5.792.935	2.662.688.71	2.662.688.71		285.7	2.782.780.24	2.638.850.82	143.929.42	43.8	316.4	128.714.77	9.8	362.680.70
New York	22.330.101	1.103.667.14	1.003.225.84	43.000.00	23.8	22.989.026.28	20.415.058.68	354.000.00	51.4	375.5	179.797.80	9.0	732.018.68
North Carolina	9.522.293	2.316.265.85	1.990.948.67	322.943.66	185.1	5.392.834.10	4.999.941.10	353.330.77	39.3	625.7	859.624.03	78.0	1.671.779.20
North Dakota	5.804.448	1.185.568.32	1.182.236.34	3.294.32	468.6	2.145.155.02	1.919.321.79	225.863.23	46.5	440.8	1.613.983.73	328.4	1.088.906.14
Ohio	15.484.592	2.141.452.27	2.096.220.71		197.1	13.863.632.43	12.775.221.43	51.410.00	69.9	348.8	519.316.37	10.2	93.833.49
Oklahoma	9.216.798	1.491.881.34	1.489.920.12		112.2	6.379.056.84	6.273.059.89		55.3	422.7	911.212.35	81.4	542.605.64
Oregon	6.106.896	2.488.491.83	2.302.156.66	98.444.47	150.4	3.548.284.40	3.276.350.18	128.021.20	37.8	153.5	408.509.78	15.8	119.879.38
Pennsylvania	18.891.004	1.292.671.11	1.275.142.80		51.3	15.863.939.07	15.536.514.87		47.3	763.1	1.328.626.91	32.6	750.719.42
Rhode Island	1.998.708	104.241.40	104.241.40		2.3	1.688.559.28	1.688.559.28		62.8	57.8	115.371.04	1.0	90.536.28
South Carolina	5.459.165.	465.522.03	465.522.03		30.0	4.012.419.10	4.009.284.47	3.134.63	48.5	360.5	458.295.22	25.5	526.063.28
South Dakota	6.011.479	1.453.187.56	1.433.846.17	19.341.39	266.2	2.957.477.42	2.649.683.60	307.793.82	28.8	412.5	834.642.10	204.0	1.093.307.13
Tennessee	8.492.619	2.043.736.55	1.830.674.25	213.062.30	97.5	5.009.525.75	4.648.365.56	361.160.19	51.9	192.6	1.442.646.74	77.8	570.932.45
Texas	24.244.024	8.173.921.58	6.863.517.91		1.007.7	14.546.596.99	13.624.462.13		40.3	873.7	1.055.547.40	37.7	2.700.496.56
Utah	4.194.708	2.575.936.17	2.537.560.60		267.2	1.322.833.39	1.296.374.14		57.2	102.9	137.171.79	6.3	223.101.47
Vermont	1.867.573	132.315.95	131.718.66		9.3	1.747.512.74	1.676.099.12	5.838.96	48.9	85.4	43.745.83	1.1	16.009.39
Virginia	7.416.757	2.022.430.39	1.972.211.54	18.234.52	148.0	4.500.288.02	4.128.116.07	119.858.30	43.5	202.0	886.111.73	29.8	430.317.66
Washington	6.115.867	2.475.339.20	2.446.222.83	3.356.82	93.0	3.535.412.21	3.535.412.21		33.1	108.7	92.379.97	5.3	41.851.99
West Virginia	4.474.234	320.707.27	320.707.27		9.3	3.554.123.66	3.523.777.92		58.6	131.1	349.106.66	12.1	280.642.15
Wisconsin	9.724.881	2.367.133.14	2.315.177.28	1.190.00	122.3	6.757.332.51	6.575.489.78	64.398.24	39.2	304.8	470.966.51	21.1	363.247.43
Wyoming	4.501.327	1.552.598.23	1.418.434.69	80.400.00	236.1	2.972.049.23	2.776.765.01	85.908.57	45.3	382.8	172.329.92	23.0	133.797.38
District of Columbia	1.918.469	497.559.88	497.559.88		5.0	1.431.548.68	1.414.564.86		51.4	7.5			6.344.26
Hawaii	1.871.062	122.232.70	109.225.57	12.994.32	6.3	1.803.971.40	1.502.765.58	251.205.82	28.0	31.4	248.693.76	6.8	10.377.09
TOTALS	394.000.000	79.774.036.09	73.201.990.29	2.645.084.43	6.985.7	283.506.260.40	263.042.470.96	8.634.305.19	48.5	13.674.4	31.148.776.25	1.718.2	26.606.762.50

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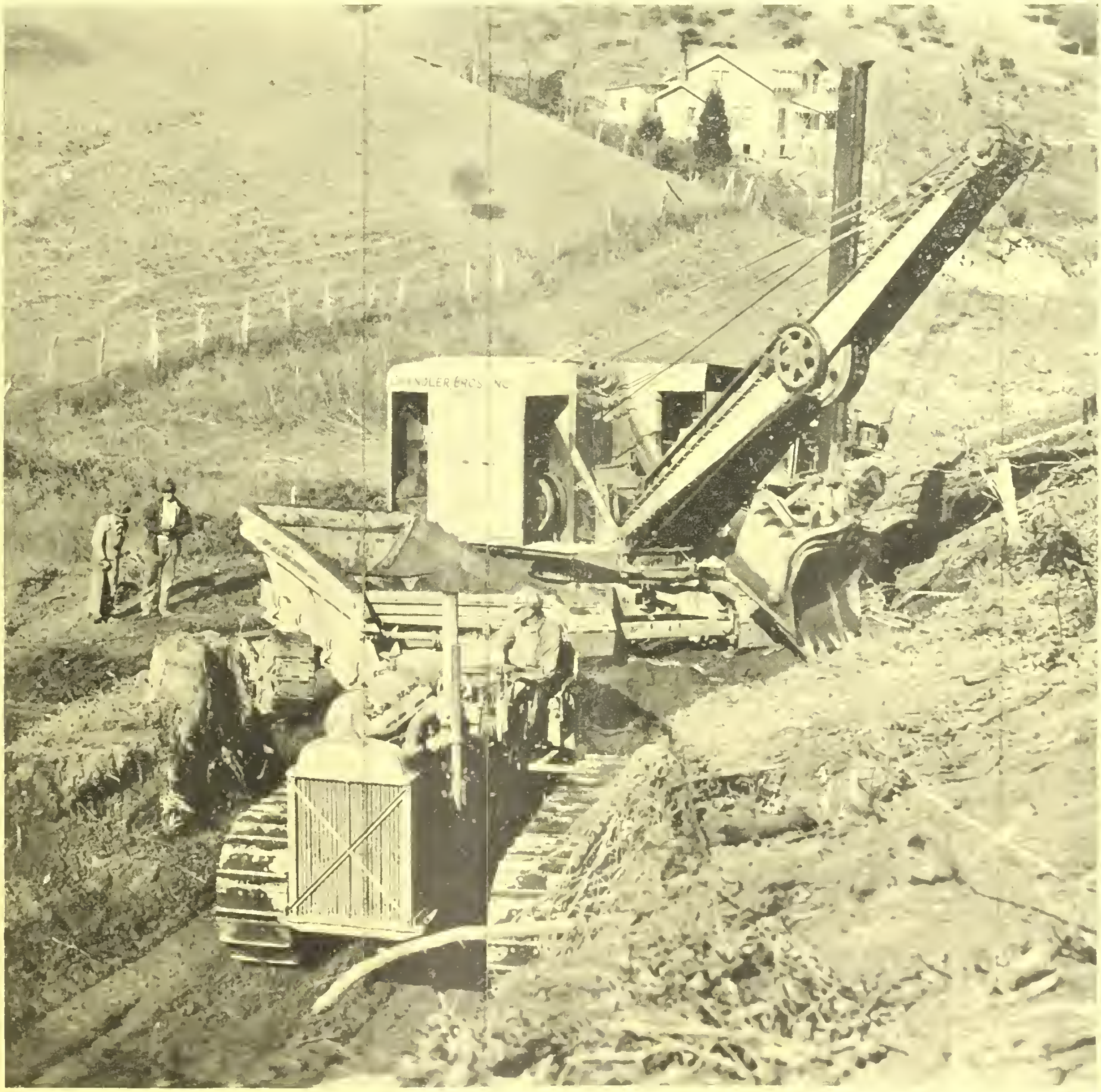

TYPICAL POWER-SHOVEL OPERATION

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the
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G. P. St. CLAIR, *Editor*

Volume 15, No. 7 September 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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POWER-SHOVEL OPERATION IN HIGHWAY GRADING

BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

Reported by **T. WARREN ALLEN**, Chief, Division of Management, and **ANDREW P. ANDERSON**, Highway Engineer

PART 2.—THE HAULING

SHOVEL LOADING TWO 5-CUBIC-YARD WAGONS.

THE SHOVEL is the key unit in a power-shovel grading outfit as commonly operated on highway work, but ordinarily it functions only in coordination with the hauling equipment. Except where casting is possible, the shovel can dig material no faster than the hauling units can carry it away to the dump and can dig only when hauling units are in position to be loaded. A high rate of production is possible only with sufficient hauling units to carry the full output of the shovel. Operation of hauling units must be so coordinated as to proceed with almost clocklike precision and without the least interference in the steady operation of the shovel.

MAINTENANCE OF EXACT BALANCE BETWEEN SHOVEL AND HAULING UNITS A DIFFICULT PROBLEM

Attainment of a high degree of efficiency in the operation of the hauling units is not easy. Studies on a great many jobs indicate that the hauling equipment, either because of shortage or improper operation, is the most general cause of reduced production. From a study of more than a hundred power-shovel grading jobs, it was found that the average power shovel on highway grading jobs spent about 20 percent of its available working time in waiting for hauling units. A part of this time oss was unavoidable because of the nature of the work but most of the delays were avoidable and should never have been permitted to occur.

Elimination of all avoidable delays without incurring the cost of carrying too much hauling equipment during much of the time is probably impossible. This is largely because there are constant but irregular variations in the hauling distance. The number of hauling units required to maintain full shovel production varies almost directly as the length of haul. The length of haul on the average grading job often fluctuates between wide limits and at such frequent intervals that the maintenance of an exact balance is economically undesirable. The speed with which hauling can be done is also variable depending upon the condition of the roadway. High speeds are seldom possible and very low speeds are often necessary. To still further complicate an already difficult situation, the characteristics which affect the rate at which the material can be dug by the shovel sometimes also change with unexpected frequency.

Since the length of haul, road conditions, and the characteristics of the material are all subject to frequent change the maintenance of an exact balance between the shovel and the hauling equipment is generally impractical, especially on light work. Although perfect balance is impossible or impractical, there is the necessity for approaching this balance as closely as conditions permit. The closeness of approach will depend very largely upon the ease with which vehicles can be added and removed in conformity with the actual requirements as they occur on the job. On work within easy access of a source of truck or wagon supply, or on jobs using two or more shovels, conformity of supply to demand can be fairly close. Lack of balance on remote jobs forced to depend on a fixed number of hauling units will be measured largely by the range of fluctuation in hauling distances as fixed by the design. A general rule for such a condition is that the amount of hauling equipment should be such that the value of the occasional delays to the shovel in waiting for hauling equipment should be equal to the value of the time spent from time to time by the hauling units in waiting for the shovel.

The operations of the hauling equipment consist of getting into position to receive the load, receiving it, taking it to the dump, dumping, turning at the dump, and returning to the shovel for another load. The time regularly consumed on each trip exclusive of the time of travel to and from the dump is called the "time constant" and is fairly uniform for any given type of equipment and set of operating conditions. Table 1 shows average time constants on a number of projects on which various kinds of vehicles of different capacities were used. The average values for the time constant as found on these jobs for the different operations vary considerably. This is to be expected. For example, the loading time will vary with the number of dipper loads required to the vehicle load, the kind of material handled, the skill of the shovel operator, and the numerous factors which affect the time of the shovel cycle.

While the time constant varies with many conditions, it is fairly uniform for a given set of conditions and its value on any job is easily determined by direct timing. It is an important factor in determining the number of vehicles most probably required to maintain a given rate of shovel operation.

Table 1.—*Average time constants for various types of hauling units based on operation with a 1- or 1¼-yard shovel*

Operation	7-yard tractor-drawn wagons	4½-yard trucks	2½-yard trucks	1¼-yard trucks
	Seconds	*Seconds*	*Seconds*	*Seconds*
Load	210	135	75	40
Turn	25	32	34	26
Unload	14	26	29	27
Turn	21	27	20	21
Waits or delays	80	55	50	44
Total	350	275	208	158

EFFICIENT OPERATION REQUIRES ATTENTION TO A NUMBER OF FACTORS

In highway grading work the time constant for the hauling units is of major importance. The hauls are generally short so that the actual speed of the vehicle usually has only a comparatively small effect as compared with the influence of the time constant. The time constant is made up of a number of individual items which are repeated with every load through the day. Their total for the day may therefore become very large.

Many contractors do not seem to realize the importance of saving seconds on the repetitive operations involved in the operation of the hauling equipment. Extension of the time constant by 2 minutes is as effective in reducing the output of the hauling equipment as an extension in the haul approximately equal to the average distance the vehicles traverse per minute of driving time. On many grading jobs the unnecessary extension of the time constant is far more than 1 minute.

Much of this delay can be eliminated by careful supervision of the operation of the hauling equipment, by keeping the traveled way in good condition, and particularly by giving attention to the conditions at the shovel and at the dump. "Bottle necks", a careless clean-up around the shovel, and restricted working area on the dump all tend to increase the time constant of the hauling equipment and thus adversely affect the output.

Another matter deserving attention is the load hauled per vehicle. There is considerable variation in the amount of material taken out per dipper load by a shovel. To place a given number of dipper loads in the vehicle on each trip is therefore a mistake, except possibly on very short hauls when there is a surplus of vehicles. Under normal road conditions, it takes as long to haul a half-loaded vehicle to the dump as it does to haul one that is fully loaded. On long-haul work there is much to be gained by hauling full loads and the shovel operator should be charged with the responsibility of seeing that the vehicles leave the shovel properly loaded, no matter how many dipper loads are required. The hauling road should always be so maintained that full loads can be handled especially on long hauls.

In selecting hauling equipment care should be taken to see that the units can be so handled that no single operation, such as turning, dumping, or maneuvering will be likely to consume more time than is required for loading. Otherwise, this operation and not the shovel controls the job output. For ordinary highway grading, where fast shovel operation is so frequently possible, a hauling unit having a capacity of less than two dipper loads should never be considered. For ease in coordinating the operation of the hauling equipment so as to maintain fast shovel operation, the individual hauling units should carry three or more dipper loads. In general, the larger the capacity of the hauling units the more easily their operation can be properly supervised and coordinated, provided, of course, that they are otherwise adapted to the job.

The conditions under which the hauling equipment must operate are usually severe and frequently extremely difficult. Hauling equipment should be extremely strong and rugged and fully able to stand up under the most trying conditions. On the average grading job replacement of hauling units can seldom be made without incurring some delay to the shovel. Reliability is therefore a valuable asset.

BACKING OF TRUCKS TO DUMP OFTEN DESIRABLE

The hauling units must be provided with an abundance of power and with traction or road grip such a will permit the full utilization of this power under the most trying conditions. Grades as steep as 25 percen are not unusual, while slippery, rough, or yielding road surfaces are so common as to be almost the rule. Fo satisfactory operation, the hauling units must have capacity to carry at least two full dipper loads, must be extremely strong and dependable, and provided with ample power and traction to operate on grades and road surfaces much more difficult than those encountered in ordinary transportation. Two or three speeds in reverse are also desirable for such vehicles as truck which are frequently backed to the dump. A fast and reliable dumping mechanism with a high dumping angle is a necessity.

On short-haul work trucks are often shuttled o backed from the shovel to the dump and then returned forward to the shovel. This eliminates two turns o the vehicle on each trip. Since each turn usually consumes from 20 to 40 seconds, this practice is advantageous until a distance is reached at which the tim lost in driving from the shovel to the dump in reverse instead of in forward is equal to the time saved by the elimination of the two turns. This is demonstrated as follows: Let—

L = the haul in feet at which shuttling the trucks ceases to be advantageous.

S = the speed in feet per minute of loaded trucks when driven forward from the shovel to the dump.

s = the speed in feet per minute of loaded trucks when backing to the dump.

K = the turning and maneuvering time in minutes saved on each round trip when trucks are backed instead of driven forward, or in other words, the difference between the time constants for trucks driven in the usual manner and when backed from the shovel to the dump.

Then

$$L=\frac{KSs}{S-s} \qquad (1)$$

For example, if the average speed of the loaded trucks from shovel to dump is 500 feet per minute and their backing speed is 300 feet per minute, and the average difference between the truck time constants is 1 minute, then $L=\frac{1\times500\times300}{500-300}=750$ feet, which is the haul within which it is more advantageous to back the trucks than to drive them in forward. If the backing speed were only 200 feet per minute and the forward speed still 500 feet per minute, then the maximum haul to which the trucks could be backed with advantage would be only 333 feet. This illustrates the importance of a relatively high backing speed in extending the distance to which shuttling may be profitable. Trucks are now made with special provisions for driving in reverse both as to the ease and comfort of the driver and the number of speeds available. The actual backing speeds attained in the field with present equipment under various road conditions are shown in tables 2, 3, 4, and 5.

TABLE 2.—*Operating characteristics of heavy trucks having drive on all four wheels*

Three 1¼-yard shovels on same job. All equipment in good condition. Material, earth and blasted rock. Grades mostly 5 to 10 percent. For all hauls below 600 feet, trucks backed to dump. Number of round trips timed, 639. Average load, pay yardage, 2.9 cubic yards]

Length of haul	Speed	
	Loaded	Return
	Feet per minute	*Feet per minute*
0 feet	210	260
00 feet	220	295
0 feet	250	302
0 feet	310	355
0 feet	365	400
0 feet	430	445
0 feet	510	420

verage time constant when trucks back to dump:	*Seconds*
Taking on load	88. 6
Dumping	30. 5
Waits and delays	23. 8
Total	142. 9

Working time lost by shovels

Class of time loss	Shovel no. 1	Shovel no. 2	Shovel no. 3
inor time losses of shovels:	*Percent*	*Percent*	*Percent*
Hauling equipment, insufficient supply	4. 1	2. 5	5. 4
Hauling equipment, operation	5. 1	2. 3	1. 4
Moving shovel within cut	7. 8	7. 4	8. 1
Shovel operator	2. 4	2. 1	1. 3
Mechanical repairs or trouble with shovel	2. 6	2. 0	2. 5
Sloping	3. 9	2. 9	4. 1
Smoothing grade and loading pit	4. 7	7. 1	8. 6
Checking grade	0. 1		
Miscellaneous	8. 7	7. 8	8. 2
ajor mechanical repairs, shovel and cable	5. 7	3. 7	3. 8

TABLE 3.—*Operating characteristics of heavy trucks on various lengths of haul*

[Trucks carried average loads of 2.5 cubic yards of pay material when working with a 1-yard shovel. All equipment in fair to good condition. Material mostly loam and clay, sticky and difficult to handle when wet. Loaded trucks backed to dump on all hauls below 750 feet]

Haul distance	Speed		Condition of hauling road
	Loaded	Return	
	Feet per minute	*Feet per minute*	
155 feet	315	325	Slippery, 10 percent grades
225 feet	377	390	Mostly fair, light grades
350 feet	435	535	Good.
420 feet	455	495	Fair, 5-percent grades
510 feet	395	418	Fair, 10-percent grades.
620 feet	407	573	Mostly fair
825 feet	660	615	Fair to good
1,050 feet	515	443	Rough, poor.
1,135 feet	756	925	Fair to good.
1,250 feet	696	518	Fair to poor.
1,400 feet	594	550	Some very rough, 10-percent grade

AVERAGE TIME CONSTANT

	Seconds
Taking on load	71. 9
Turn (long hauls)	20. 9
Dump load	28. 8
Turn (long hauls)	18. 7
Waits and delays	55. 9
Total	196. 2

WORKING TIME LOST BY SHOVEL

	Percent
Minor time losses:	
Hauling equipment, insufficient supply	14. 9
Hauling equipment, faulty operation	4. 5
Moving shovel within cut	5. 2
Shovel operator	. 7
Mechanical repair and trouble with shovel	. 7
Sloping	3. 7
Smoothing grade and loading pit	3. 6
Major mechanical repairs to shovel and cable	3. 3

SPEED OF HAULING UNITS VARIES WITH JOB CONDITIONS

When two or more shovels are used on the same job they should, if possible, be so located that hauling units can be readily exchanged between them, and every effort should be made to schedule the work so that when one shovel is on long hauls the other will be on relatively short-haul work. The hauling units can then be shifted in accordance with the actual requirements at the shovels. The total number of hauling units for the shovels should be the same as though each operated independently with one constantly on long hauls and the other on short hauls. By this method the working time of both the shovels and the hauling units can be utilized more fully. Since the equipment and the personnel remain constant, any increase in production obtained is practically a clear gain. Jobs have been found on which this simple expedient added nearly 10 percent to the average daily production.

Dressing Slopes by Hand and the Same Slope Five Days Later as Washed by Rain. Too Much Refinement Increases Cost Without Producing Advantages.

Table 4.—*Effect of length of haul and road condition on average hauling speed*

[2½-yard trucks in fair to good condition, working with 1-yard shovel. Common excavation. Hauls below 600 feet all by backing loaded trucks to dump]

Length of haul	Speed		Road condition
	Loaded	Return	
	Feet per minute	*Feet per minute*	
155 feet	373	423	Good.
170 feet	310	318	Fair surface, slippery steep downgrade.
200 feet	497	480	Good.
200 feet	250	362	Very rough.
210 feet	262	370	Poor road, rough with steep downgrade.
285 feet	427	427	Do.
350 feet	594	580	Good.
410 feet	524	530	Fair.
500 feet	292	600	Rough and slippery with 3 percent upgrade.
500 feet	518	700	Good to fair, nearly level.
600 feet	632	838	Good.
800 feet	990	717	Good.
1,000 feet	437	559	Poor.
1,125 feet	890	1,160	Good.
1,150 feet	758	1,045	Good.
1,250 feet	695	517	Fair.
1,400 feet	586	550	Fair.

Average time to—	*Seconds*
Load	74
Dump	29
Make two turns	51

Table 5.—*Average speed of heavy trucks on short hauls*

[5-ton trucks loaded with 3 cubic yards of blasted rock and earth operating on about 5-percent grades by backing to dump and returning in forward. Trucks in good mechanical condition and hauling road well and systematically maintained. Trucks working with a 1¼-yard shovel]

Length of haul:	*Average round-trip speed—feet per minute*
0 to 50 feet	232
50 to 100 feet	250
100 to 200 feet	274
200 to 300 feet	336
300 to 400 feet	384
400 to 500 feet	435
500 to 600 feet	455

The road speeds for any given vehicle are affected by many factors, the most important of which are the condition of the road surface, grades, and lengths of haul. Road speeds under different conditions are given in tables 3, 4, 6, 7, 8, 9, 10, 11, 12, and 13. For different vehicles, the type, condition, and size are the most important of the factors which affect speed. The extent to which these factors frequently affect the hauling speed is indicated in tables 2, 4, 6, 10, 12, and 14.

Most of the hauling on grading work is done at an average speed of less than 500 feet per minute for trucks, about 300 feet per minute for large tractor-drawn wagons, and about 240 feet per minute for ordinary horse-drawn dump wagons. Average round-trip speeds as high as 900 feet per minute for trucks, 400 feet per minute for tractor-drawn wagons, and 250 feet per minute for horse-drawn wagons are rarely attained, except for short periods and under exceptionally favorable conditions.[1] Tables 3, 7, 10, 12, and 14 show typical average speeds regularly maintained on a number of jobs using various kinds of vehicles.

LARGE CAPACITY HAULING UNITS OFTEN USED

In a summary of studies of power-shovel operation in highway grading compiled in 1927,[2] it was found that the prevailing size of the shovels then in use had a dippe of three-quarters yard capacity. Teams and bottom-dump wagons were by far the most common type o hauling equipment. Trucks were used to some extent the solid-tire type predominating. Tractor-draw wagons of 4 or 5 cubic yards capacity were found o comparatively few jobs. At the present time (1933) the 1¼-cubic-yard shovel is found on a majority of job and the 1½-yard shovel is observed as frequently as th three-quarter-yard shovel. The team and wagon ha practically disappeared while the large truck equippe entirely with pneumatic tires had become the mos common type of hauling equipment, followed by th large tractor-drawn wagon, now usually of 6 or 8 cubi yards capacity and generally provided with crawle treads.

In highway grading the hauls for most of the materi are usually comparatively short so that road speed i not a prime factor in obtaining production from th hauling units. High speeds are generally impossibl because of road conditions. Load-carrying ability ease of operation, and dependability are more importa factors. Recent developments in specialized haulin units have aimed at combining, in a rather low-spee vehicle, large capacity, rapid unloading, easy turnin ability, and high mechanical dependability. A numbe of manufacturers have developed special hauling unit designed particularly for operation with the pow shovels, elevating graders, and draglines.

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[1] For additional data on hauling with teams and wagons, see Public Road March 1928.

[2] Power Shovel Operation in Highway Grading, Public Roads, February, Marc and April 1928.

Table 6.—*Operation characteristics of 7- and 8-yard tractor-drawn wagons*

[Three 1¼-yard shovels on same job. All equipment in good condition. Material, largely sandy earth, some frozen. Heavy trucks used for some very long-haul work. Heaviest grades about 8 percent. Wagons carried an average of 7 cubic yards of pay material per load, trucks carried 4.4 cubic yards]

Hauling unit	Grade	Length of haul	Speed: Loaded	Speed: Return	Speed: Return distance
	Percent	*Feet*	*Feet per minute*	*Feet per minute*	*Feet*
Tractor-drawn wagons	−8	305	270	230	350
Do.	−7	525	273	238	590
		600	327	347	630
Do.	−5	700	320	326	750
Do.	−1	840	334	348	890
Do.	−6	1,025	380	393	1,010
		1,040	388	385	1,070
Heavy trucks	−2	6,400	1,414	1,416	6,400
Do.	+4	6,800	1,275	1,668	6,800

TIME CONSTANT

	Trucks	Wagons
Taking on load .... seconds	135.6	214.6
Turning at fill .... do	50.7	21.3
Dumping load .... do	40.4	20.0
Turning at shovel .... do	43.4	25.7
Waits and delays .... do	41.0	83.0
Total .... do	311.1	364.6

WORKING TIME LOST BY SHOVELS

Class of time loss	Hauling by wagons	Hauling by trucks
	Percent	*Percent*
Minor time losses of shovels:		
Hauling equipment, insufficient supply	4.1	17.3
Hauling equipment, faulty operation	3.1	1.6
Moving shovel within cut	5.0	4.3
Shovel operator	.6	.9
Mechanical repairs and trouble with shovel	2.9	1.9
Sloping	4.3	1.5
Smoothing grade and loading pit	2.7	2.9
Checking grade	.5	.2
Miscellaneous	3.2	3.8
Major mechanical repairs, shovel and cable	2.0	2.9

Table 7.—*Operating characteristics of heavy trucks and tractor-drawn wagons*

[Two 1¼-yard shovels on one job. All equipment in good condition. Material, earth and blasted limestone. Rates of production, 85 and 110 cubic yards per working hour for the two shovels. Grades light. Average load, 4 cubic yards for heavy trucks and 8 cubic yards for wagons]

Heavy trucks: Length of haul	Heavy trucks: Speed: Loaded	Heavy trucks: Speed: Return	Tractor-drawn wagons: Length of haul	Tractor-drawn wagons: Speed: Loaded	Tractor-drawn wagons: Speed: Return
	Feet per minute	*Feet per minute*		*Feet per minute*	*Feet per minute*
150 feet	240	265	200 feet	235	290
400 feet	296	220	290 feet	279	220
950 feet	966	704	370 feet	310	320

TIME CONSTANT

	Heavy trucks	Tractor-drawn wagons
Taking on load .... seconds	122	239
Turning .... do	8	16
Dump load .... do	18	9
Turning .... do	53	58
Delays and waits .... do	127	237
Total gross time constant .... do	328	559

WORKING TIME LOST BY SHOVEL

Class of time loss	Percent	Percent
Minor time losses:		
Hauling equipment, insufficient supply	3.3	1.0
Hauling equipment, operation	3.0	.6
Moving shovel within cut	9.8	5.5
Shovel operator	1.0	1.2
Mechanical repair or trouble with shovel	1.8	2.2
Clean pit and trim slopes	5.4	6.8
Miscellaneous	6.3	3.6
Major mechanical repairs	4.1	.5

Note.—One man did all the sloping.

Table 8.—*Time constants and average round-trip speeds of trucks operating with 1¼-yard shovel*

[Hauling road maintained over fills and through cuts with bulldozers equipped with 8-foot blades. On hauls exceeding 1,200 feet a water truck was used to sprinkle the road and keep it firm. When required, 1 or 2 laborers filled holes, ruts, etc. Grades generally about 5 percent]

Operation	Large trucks, 5.7 cubic yards pay load: Short hauls, no turns	Large trucks, 5.7 cubic yards pay load: Long hauls, 2 turns	Smaller trucks, 4 cubic yards pay load: Short hauls, no turns	Smaller trucks, 4 cubic yards pay load: Long hauls, 2 turns
	Seconds	*Seconds*	*Seconds*	*Seconds*
Load	138	138	120	120
Dump	34	34	38	38
Turn		81		113
Average net time constant	172	253	158	271

AVERAGE ROUND-TRIP SPEEDS, FEET PER MINUTE

Large trucks:	
Downgrade on hauls over 1,250 feet	1,050
Downgrade on hauls between 400 and 800 feet, no turns	262
Upgrade on hauls over 1,500 feet	714
Smaller trucks:	
Downgrade on hauls over 1,250 feet	810
Downgrade on hauls between 400 and 800 feet, no turns	301

There are two types of units in general use—those drawn by tractors and those provided with their own power units. Crawler treads are generally used on the tractor-drawn wagons and are also found on the other type. The capacity of these units usually varies from 3 to 10 or even 12 cubic yards. The sizes generally used with power shovels range from 5 to 8 cubic yards. The operation characteristics of tractor-drawn wagons are shown in tables 6, 7, 9, and 14.

Where the grades are easy and the hauling conditions otherwise favorable, two of these wagons are sometimes drawn by one large crawler-tractor. Two wagons are seldom drawn by one tractor where the grades are steep, because of the difficulty of control on the descent. On good or fair roadways and light grades two wagons can be drawn at practically the same speed as one; but it is general practice to shift to one wagon when travel becomes dfficult. (See table 4.)

The observations made are not a conclusive proof that under favorable conditions a tractor can haul two wagons as fast as one since the conditions under which the 1- and 2-wagon operations were studied were not strictly similar. On elevating-grader work on which both 1- and 2-wagon trains were used there was noted a tendency to use two wagons until the hauling road became so bad that 2-wagon trains could not be handled or the haul became so short that a single wagon was more than sufficient. The 1-wagon trains were operated only when the road was poor or when there was no need for speed.

TABLE 9.—*Variations in hauling speed with length of haul*

[7-yard crawler-tread wagons with heavy crawler tractors working with 1¼-yard power shovel. Road good, with easy return grades. Average load of pay material, 6.75 cubic yards]

Length of haul	Speed	
	Loaded	Return
	Feet per minute	*Feet per minute*
130 feet	270	269
350 feet	288	279
500 feet	333	314
1,000 feet	354	338

NET TIME CONSTANT

	Seconds
Load	205
Two turns	30
Unload	13
Total	248

TABLE 10.—*Variation of hauling speed with steepness of grade, length of haul, and condition of road surface*

[Heavy trucks carrying 4.0 and 5.7 cubic yards pay material per load, working with 1¼-yard power shovel. Trucks in good condition]

Length of haul	Grade	Speed		Size of load	Condition of road
		Loaded	Return		
	Percent	*Feet per minute*	*Feet per minute*	*Cubic yards*	
150 feet	−6	380	178	5.7	Rough.
150 feet	−6	220	247	4.0	Do.
200 feet	−6	174	315	5.7	Rough and slippery.
350 feet	−9	220	360	4.0	Rough to fair.
1,250 feet	−5	660	662	4.0	Fair.
1,400 feet	−5	680	780	4.0	Good.
1,500 feet	+5	393	720	5.7	Fair.
1,550 feet	+4	405	950	5.7	Do.
1,600 feet	+4	453	1,090	5.7	Good.
1,800 feet	+5	433	1,190	5.7	Fair.
2,000 feet	+5	410	1,200	5.7	Do.
2,700 feet	−5	1,285	847	5.7	Good.
2,700 feet	−5	1,280	708	4.0	Do.
4,000 feet	−5	970	830	4.0	Fair.
4,000 feet	−5	950	900	5.7	Good.

TABLE 11.—*Average speeds on steep grades*

[5-ton trucks backing to dump and returning in forward on hauls of 300 feet with an average of 15-percent grade, one section about 50 feet long was over 22 percent. Trucks in good condition. Road fairly smooth and hard. 1-yard shovel. Studies extended over 3 days]

Day of study	Backing downgrade	Returning upgrade
	Feet per minute	*Feet per minute*
First	347	397
Second	284	342
Third	333	427

AVERAGE TIME CONSTANT

	Seconds
Taking on load	138.7
Dumping load	34.0
Maneuvering on dump	19.0
Total	191.7

[Average grade 12 percent, but one section of 100 feet of 25 percent grade, haul about 350 feet]

Day of study	Backing downgrade	Returning upgrade
	Feet per minute	*Feet per minute*
First	229	370
Second	186	309

TABLE 12.—*Effect of road condition and length of haul on hauling speed of 1½-ton trucks working with power shovel*

[Trucks in fair to good condition. Mostly easy downgrades]

Length of haul	Speed		Condition of road
	Loaded	Return	
	Feet per minute	*Feet per minute*	
150 feet	450	617	Somewhat rough.
170 feet	341	344	Very poor.
275 feet	475	528	Rough.
300 feet	475	617	Do.
320 feet	475	502	Rough and muddy.
325 feet	528	475	Rough.
360 feet	617	800	Mostly fair, some rough.
600 feet	862	818	Fair, easy downgrade.
720 feet	750	660	Fair, with steep downgrade.
1,050 feet	1,190	1,135	Fair to good, some downgrade.

TABLE 13.—*Operating characteristics of heavy trucks working with 1-yard shovel under adverse conditions*

[Mechanical equipment in fair condition. Road fair to poor and very poor. Trucks backed to dump. Average load of pay material, 2.5 cubic yards]

Road condition	Fair	Poor	Very poor	Fair
Length of haul ... feet	320	420	530	550
Loaded speed ... feet per minute	345	350	250	425
Return speed ... do	330	395	360	490
Time constants for various operating conditions:				
Taking on load ... seconds	79	78	71	66
Turning ... do		35	42	36
Dumping load ... do	57	33	27	28
Turning ... do		38	20	47
Waits and delays ... do	13	41	20	51
Total time constant ... do	149	225	180	228

AVERAGE PERCENTAGE OF WORKING TIME LOST

	Percent
Minor time losses of shovel:	
Hauling equipment, insufficient supply	2.9
Hauling equipment, faulty operation	2.3
Moving shovel within cut	2.6
Shovel operator	.4
Mechanical repairs and trouble with shovel	1.1
Checking grade	
Miscellaneous	3.2
Major mechanical repairs, shovel and cable	13.2

MAINTENANCE OF HAULING ROAD IMPROVES EFFICIENCY OF OPERATION

It is not difficult to show that the condition of the road surface has considerable influence on the station-yard cost of hauling, but it is difficult to obtain data as to the reduction in hauling costs which can be obtained by better maintenance of the road surface. Systematic maintenance of the hauling road is not a common practice among grading contractors. Only a few seem to have discovered that it pays to maintain a smooth surface on the hauling road and assign men and equipment specifically to road maintenance. A blade grader is most frequently used but in some cases the bulldozer is used whenever it is not busy on the dump. Systematic maintenance of the hauling roads frequently results in a sufficient increase in operating speed to permit the use of fewer hauling units, more regular operation of the shovel due to the elimination of hauling delays, and greatly reduces the wear and tear on the hauling vehicles.

Tables 5, 8, 13, and 15 are based on time studies on a number of jobs and show variations in road speeds which may be expected with changes in road conditions. These data indicate results which may be expected from adequate maintenance of the hauling road. The advantages of road maintenance are: (1) Faster speed, permitting more loads to be hauled in a given time;

TABLE 14.—*Operating characteristics of 7-yard tractor-drawn wagons*

[Two 1¼-yard shovels, working in common excavation. All equipment in good condition. Number of round trips timed, 628. Average load per wagon of pay yardage, 6.75 cubic yards. Grades light]

Length of haul	Speed	
	Loaded	Return
	Feet per minute	*Feet per minute*
270 feet	285	283
325 feet	302	298
400 feet	325	310

AVERAGE TIME CONSTANT

	Seconds
Taking on load	195
Turning, at dump and shovel	31
Dumping	11
Waits and delays	32
Total	269

WORKING TIME LOST BY SHOVELS

Class of time loss	Shovel no. 1	Shovel no. 2
Minor time losses of shovels:	*Percent*	*Percent*
Hauling equipment, insufficient supply	1.3	14.8
Hauling equipment, improper operation	1.2	2.6
Moving shovel within cut	10.0	8.4
Shovel operator	.5	2.0
Mechanical repair and trouble with shovel	1.5	1.7
Sloping	5.2	3.6
Smoothing grade and loading pit	2.7	5.5
Checking grade		.3
Miscellaneous	.7	3.5
Major mechanical repairs to shovel and cable	4.2	3.2

When the average round-trip wagon speed was 283 feet per minute for drawing 1-wagon trains, this was reduced to 259 feet per second on changing to 2-wagon trains. The loading time was increased from 195 seconds to 405 seconds.

TABLE 15.—*Operating speed of heavy trucks on steep grades*

[Trucks operating with 1½-yard shovel and carrying average load of 3.5 cubic yards of pay material. All equipment in good condition. Hauling road which had one or more sharp curves maintained fairly smooth]

Grade	Length of haul	Loaded	Return
	Feet	*Feet per minute*	*Feet per minute*
Minus 25 percent	500	310	283
Do	550	305	290
Minus 20 percent	650	330	300
Do	900	350	345
Minus 6 percent	700	550	565

TIME CONSTANT

	Seconds
Taking on load	89
Turning	34
Dumping load	29
Turning	30
Waits and delays	84
Total	266

WORKING TIME LOST BY SHOVEL

	Percent
Minor time losses of shovel:	
Hauling equipment, insufficient supply	4.3
Hauling equipment, faulty operation	5.3
Moving shovel within cut	2.4
Shovel operator	.4
Mechanical repairs and trouble with shovel	1.8
Sloping	1.1
Smoothing grade and loading pit	.1
Miscellaneous	7.8
Major mechanical repairs, shovel and cable	.2

(2) larger loads; (3) greater regularity in operation, thus reducing delays at the shovel; and (4) less wear and tear on the hauling equipment.

Figure 1 shows graphically the average hauling speeds attained before and after a road was smoothed and shaped with a blade grader. The grade which averaged about 4 percent was quite rough before the blading and the average speed over it was only 630 feet per minute for loaded vehicles and 658 feet per minute for unloaded vehicles in returning up the grade. As a result of work with a blade grader the speed of the loaded vehicles was increased to 1,050 feet per minute and the speed of the unloaded vehicles was increased to 965 feet per minute. The improvement of the earth road resulted in an increase of 66.7 percent in the speed of the loaded vehicles and an increase of 47 percent in the return speed of the empty vehicles up the grade. While this is only one example and involved only heavy trucks carrying 3½ cubic yards of material, it is believed that conditions were typical of those to be found on many projects. Sprinkling the roadway in very dry weather has sometimes been found advantageous.

Aside from rough or soft yielding road surfaces, the chief deterrent to speed is steep grades. Sometimes all of these conditions are combined to form exceptionally bad hauling conditions. The effect of ascending grades is to gradually decrease the hauling speed at a rate somewhat faster than the increase in grade, as successive points are reached at which shifts must be made to lower gear ratios, until finally a point is reached at which the vehicle can no longer haul the load. The only recourse then is to reduce the load. In highway grading work, however, the steepest grades are almost invariably descending grades for the loaded vehicle. The limiting grade is therefore usually fixed by the climbing ability of the unloaded vehicle while both the size of the load and the speed of the loaded vehicle on the descent are largely fixed by safety considerations rather than the hauling ability of the vehicle. The extent to which grades reduce actual hauling speed is indicated in tables 4, 6, 10, 15, 16, and 17. Figures 1 and 2 illustrate the way in which the rate of speed varies on a grade.

Soft or yielding road surfaces have much the same effect in reducing the speed and load-carrying capacity of the hauling vehicles as a grade. As the road surface

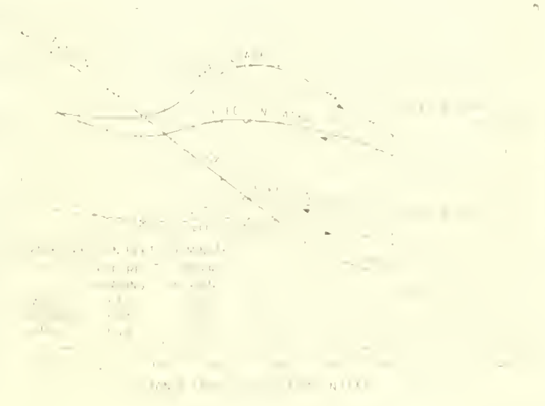


FIGURE 1. SPEEDS AT WHICH 5-TON SOLID-TIRED TRUCKS IN GOOD CONDITION OPERATED BEFORE AND AFTER MAINTENANCE WITH A BLADE GRADER. CURVES SHOW SPEEDS AT VARIOUS POINTS ALONG 2- TO 4-PERCENT GRADE.

TABLE 16.—*Speed of truck operation on long, moderate grades*

[Hauling excavation from 1¼-yard shovel, 5-ton trucks, good condition. Pay load, 3.8 cubic yards. Long 6-percent grade, generally fair condition]

Length of haul	Loaded	Return
	Feet per minute	*Feet per minute*
800 feet	800	643
1,000 feet	870	828
1,100 feet [1]	335	387
1,100 feet	1,055	970
1,300 feet [2]	828	1,100
2,000 feet [3]	1,020	950

[1] Effect of narrow road which prevented easy passing of loaded and empty trucks.
[2] Road somewhat slippery, requiring caution on downgrade.
[3] Part of road somewhat spongy.

AVERAGE TIME CONSTANT

	Seconds
Load	110
Turn and back at dump	53
Dump load	11
Turn and spot at shovel	31
Waits and delays	40
Total	245

TABLE 17.—*Effect of rough road surface on increase in speed with increase in distance*

[Trucks hauling 2 cubic-yard loads of blasted rock down rough 5 percent grade. Trucks in fair to good condition; road surface very rough entire distance]

Length of haul	Speed	
	Loaded	Return
	Feet per minute	*Feet per minute*
320 feet	370	317
600 feet	370	387
1,000 feet	440	395
1,100 feet	457	397
1,250 feet	440	405

gives or depresses under the wheels of the moving vehicle there is the equivalent of an obstruction in front of the wheels which is effective in reducing speed. In very soft ground loads must be drastically reduced or hauling discontinued until the road becomes more stable. Hauling speeds are sometimes seriously reduced by the slipperiness of the road surface. Some gumbo and clay soils become extremely slippery and difficult to travel over when wet only on the surface.

DETERMINATION OF REQUIRED NUMBER OF HAULING UNITS NOT A DIFFICULT PROBLEM

Attention has been called to the practical difficulties in keeping the shovel supplied with hauling units. Some of these difficulties are inherent in the nature of the work. Others can be ascribed to the contractors. On some jobs, however, the extent and frequency of variations in length of haul are largely due to failure of the designing engineer to appreciate the extent to which such fluctuations affect the cost of performing the work. The hauls on a job for which the average haul is 500 feet may be so distributed that hauling equipment sufficient to haul all of the material 1,000 feet must be provided. Even under favorable conditions this extra hauling equipment will probably add 3 or 4 cents per cubic yard to the unit cost of the job without adding any compensating value to the completed work.

It is believed that designers can profitably devote more attention to reducing variations in haul distances to permit more effective use of hauling equipment.

The length of haul is usually short—seldom more than 600 or 800 feet as the average haul for most of the yardage. The difficulty is that the average haul is quite different from the actual hauls the contractor must make to place the materials in conformity with the requirements. The haul distance may readily vary from practically zero to 2,000 or 3,000 feet and in extreme cases to 4,000 or 5,000 feet for a relatively small part of the material.

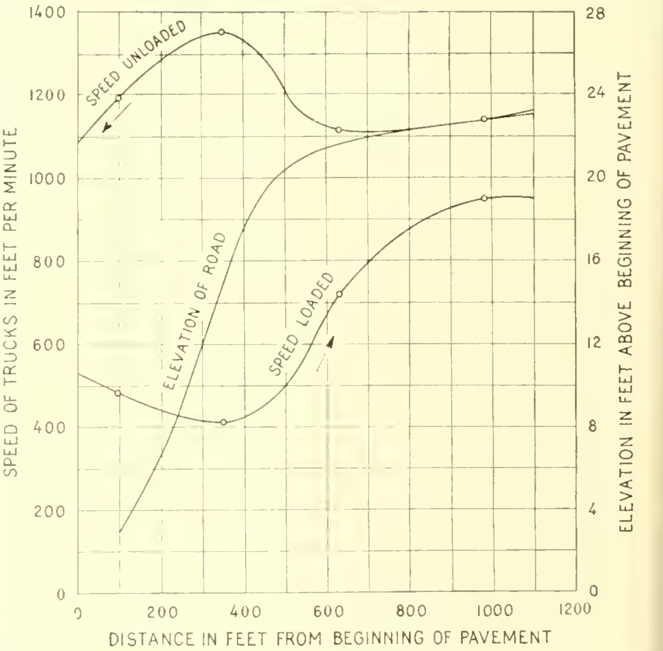


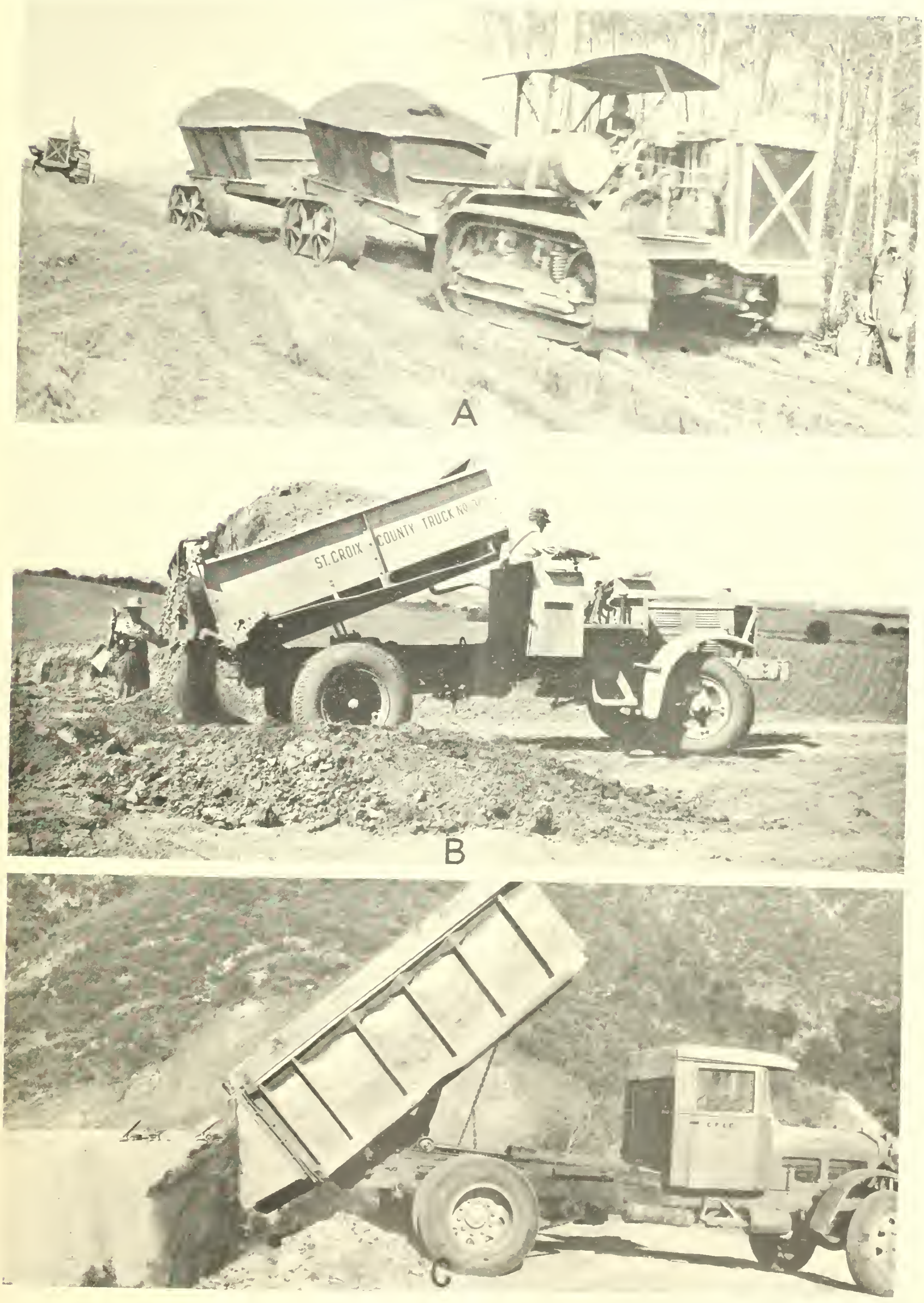
FIGURE 2.—SPEED OF 5-TON SOLID-TIRED TRUCKS HAULING OVER OLD BITUMINOUS MACADAM SURFACE. SHOVEL LOCATED ABOUT 100 FEET FROM HIGHWAY.

These varying lengths of haul, in which the rate of variation is seldom uniform, cause difficulties in maintaining a correct number of hauling units not found in other lines of transportation. As the length of haul changes, the number of hauling units should be increased or decreased if perfect balance is to be maintained. In practice, this is usually impossible. The changes in haul lengths are too frequent to make this practical, and the number of hauling units maintained on the job is usually almost constant from day to day and frequently for the whole job. This requires the selection of such number of vehicles that when the hauls are long the supply will be insufficient and the shovel will lose time waiting for vehicles, while on short hauls the supply will be too large and the hauling vehicles will lose time waiting for the shovel. When this arrangement is necessary, the number of vehicles selected should be such that the job can be completed at a minimum cost. How this number can be determined will be shown later.

Determination of the number of hauling units of given size and kind required for a given set of operating conditions is not difficult. Values for the necessary factors can be determined readily by timing operations with a stop watch. Only factors which can readily be determined and checked from time to time need be used in the following method: Let

S=average round-trip speed of hauling unit in feet per minute exclusive of all stops, turning, switching, etc.

T=total time constant in minutes; that is, the sum of the average time required each round trip to take on the load, dump it, turn and maneuver both at the dump and shovel, and all regular stops and delays.



A, Two 5-Cubic-Yard Wagons Drawn by a Tractor; B, Truck Designed for Easy Backing; C, Truck Dumping About 1½ Cubic Yards of Material

t = time in minutes required to take on load, or longest regular stop or delay if this exceeds the loading time.

L = length of haul in feet.

N = number of vehicles required to just keep shovel in continuous operation for any haul, L.

A = rental value of hauling vehicle, including driver and operating cost, in cents per hour of working time.

W = average pay load, in cubic yards, carried by vehicle.

C = cost of hauling in cents per cubic-yard station.

K = cost in cents per cubic yard for hauling the material a distance L.

Q = number of loads hauled per hour by one vehicle.

Then

$$N=\frac{2L}{St}+\frac{T}{t} \qquad (2)$$

$$Q=\frac{60S}{2L+ST} \qquad (3)$$

$$K=\frac{A}{60W}\left(\frac{2L}{S}+T\right) \qquad (4)$$

$$C=\frac{5A}{3W}\left(\frac{2}{S}+\frac{T}{L}\right) \qquad (5)$$

Formula 2 gives the number of vehicles required to just keep the shovel in continuous operation when it is working at the rate indicated by the factor t, which is the average time required to load each vehicle. Care must be taken, however, that the operation of the hauling units is such that no regular stop exceeding t is permitted; otherwise this stop, and not the loading rate of the shovel, becomes the pacemaker. As an example: With wagons having an average round-trip speed of 400 feet per minute, a time constant, T, of 5 minutes, and which can be loaded by the shovel in $2\frac{1}{2}$ minutes, the number of hauling units required for a haul of 1,000 feet is determined by formula 2 as follows:

$$N=\frac{2\times 1000}{400\times 2.5}+\frac{5}{2.5}=\frac{2000}{1000}+2=4$$

Four wagons will thus be required under these conditions to maintain full shovel production. An additional vehicle must be added or taken off whenever the haul changes by the distance $\frac{St}{2}$, in this case

$$\frac{400\times 2.5}{2}=500 \text{ feet.}$$

CONDITIONS REQUIRING ADDITIONAL UNITS ANALYZED

The addition of another vehicle at the first indication of insufficient hauling equipment is not economical. This is especially true when vehicles of large capacity are used. To examine this question, let

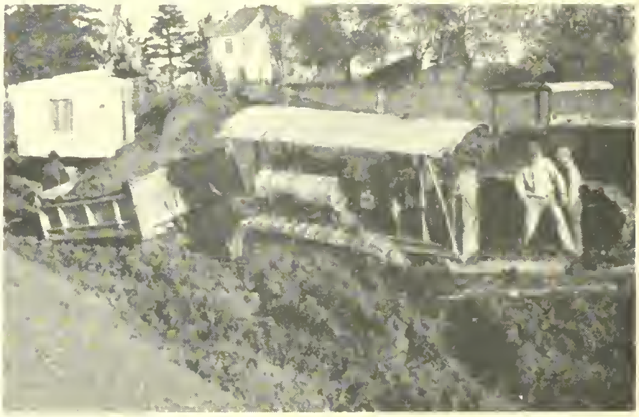
D = total rental or operating cost to the contractor per hour of working time of vehicle to be added.

G = total cost to the contractor per hour of working time of his working force and equipment, including dump operations, before vehicle is added.

H = the number of minutes per hour which shovel can afford to wait for hauling units before this waiting becomes more expensive than adding another hauling vehicle.

Then

$$H=\frac{60D}{G+D} \qquad (6)$$



Hauling Under Adverse Conditions.

A contractor who is using trucks costing \$3 per hour of working time notices that because of the increasing haul distance his shovel is spending time waiting for hauling units. The operating cost of the equipment and force he now has, including shovel, hauling and dump operations, amounts to \$20 per working hour. How much time can he afford to let the shovel lose before it will be economical to provide another vehicle? From the above (formula 6), we have $H=\frac{60\times 3}{20+3}=7.8$. He can therefore afford to lose no more than 7.8 minutes an hour before the value of the losses in reduced production will exceed the cost of the additional vehicle.

In Heavy Work the Bulldozer is Essential to Orderly Dump Operation.

When the shovel is losing 7.8 minutes an hour in waiting for trucks, then the addition of another truck at \$3 an hour will neither increase nor decrease the unit cost of handling the material at this haul. The extra truck should be added whenever this length of haul is exceeded. By permitting the shovel to work continuously, the added truck will permit handling all the material with hauls longer than this at less cost than would be possible without the added truck.

The only factor to be watched in order to know when it becomes economical to add another hauling unit is the time lost by the shovel in waiting for vehicles. Consequently, no contractor should be without a stop watch, or fail to make regular use of it. If, however, a determination of the time lost by the shovel while waiting for hauling units is impractical, the length of haul at which another hauling unit should be added can be determined from the following formula in which all the terms have the same significance as previously given.

$$L' = \frac{St}{2}\left(N - \frac{T}{t} + \frac{ND}{G}\right) \qquad (7)$$

Here, L' is the length of haul at which it becomes economical to add another vehicle

Large-capacity hauling units are frequently used with the power shovel, and the efficiency with which they can be operated is important. Under ordinary field conditions, the vehicles cannot maintain perfect operation. Drivers become careless or inattentive and the vehicles require attention from time to time.

Aside from vehicle delays which arise from having too many vehicles, there will be delays imposed by the shovel and delays due to the trucks themselves or their operators. On a poorly managed job the total of these delays may be very large, and even on well-managed jobs they may consume from one-third to one-half of the total available working time of the trucks.

Table 18 gives the time losses on a fairly well-managed job for two kinds of trucks operating with different shovels. All the trucks were in good to fair condition. The 3½-ton trucks operating with the first shovel carried an average load of 3 cubic yards of pay material while the 5-ton trucks operating with the second shovel carried average loads of 4½ cubic yards of pay material. The average haul was about 1,000 feet for the first and about 700 feet for the second. Grades were frequently steep but the road, pit, and dump were maintained in better than average condition. The studies cover a total of 1,467 truck-hours and 1,202 truck-hours, respectively.

Table 18 indicates the necessity of taking time losses into account in determining the time constant to be used in formula 2 for determining the number of hauling units required. The ordinary shovel delays are, of course, reflected in the average time required to take on load. All regularly occuring delays to the hauling equipment which cannot be eliminated must be added to the time constant, otherwise the indicated number of vehicles will be insufficient. In determining the truck delays to be included in the time constant, care should be taken to exclude all delays resulting from having too many vehicles. Regular waits at the shovel indicate an oversupply, but regular delays at the dump are an indication of improper dump operation. If the trouble cannot be removed these delays at the dump must be included in the time constant.

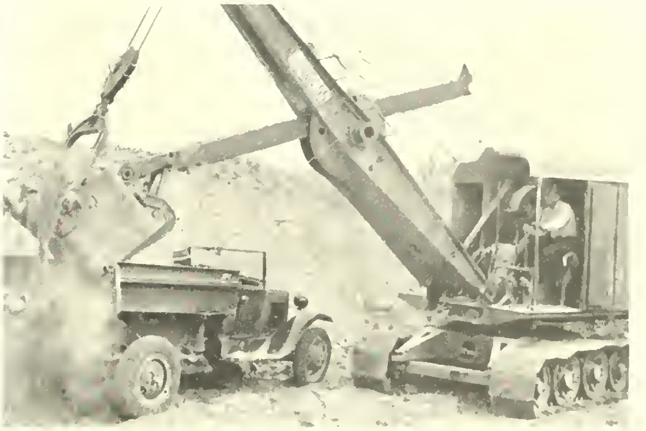
METHOD OF DETERMINING REQUIRED NUMBER OF HAULING UNITS ILLUSTRATED

The number of hauling units to be maintained with the shovel in order to complete the job at the lowest possible cost deserves more attention than this problem usually receives. The heavy trucks or tractor-drawn wagons generally used are usually considered to cost from $2 to $3 per hour, sometimes more. They are too expensive to warrant the use of more than are necessary. On the other hand, a shortage of only one vehicle on a moderate haul may readily reduce shovel production by 20 to 30 percent. The number of hauling units which the contractor maintains on the job therefore bears a very definite relation to the profits which the job may be made to yield.

TABLE 18.—*Percentage of available working time lost by trucks working with power shovels in well-blasted rock, shale and earth, and general data on operation*

[All trucks in good to fair condition]

Cause of delays to trucks	Working time lost by trucks working with	
	Shovel 1	Shovel 2
Major stops each of 15 or more minutes in duration	*Percent*	*Percent*
Shovel casting	0.3	2.8
Shovel down, trucks waiting	15.1	12.5
Truck down, adjustments, repairs, tires, etc	13.2	5.1
Too many trucks on job	6.7	11.9
Total major time loss	35.3	32.3
Minor stops each less than 15 minutes in duration		
Operating delays on road and at dump	2.3	2.6
Waits to get under shovel	14.6	11.1
Total minor delays	16.9	13.7
Actual productive working time of trucks	47.8	54.0
General data:		
Total available trucks, hours	1,467.0	1,202.5
Average pay yardage per load, cubic yards	3.0	4.5
Average length of haul, feet	970	675
Average round-trip speed, feet per minute	520	500
Average net loading time, minutes	2.5	3.1
Total pay yardage hauled, cubic yards	23,111	31,090


A SMALL TRUCK BODY REQUIRES CAREFUL SPOTTING OF THE DIPPER AND INCREASES DUMPING TIME.

The number of hauling units required for a particular set of operating conditions and length of haul can be readily determined by means of formula 2. This, however, offers no direct solution of the problem of the number of hauling units to be brought on a job where conditions permit few, if any, changes to be made during the progress of the work. For this, a more detailed procedure is necessary.

To analyze this problem the quantities which must be hauled each given distance are first tabulated. These quantities and distances can most readily be taken from a mass diagram and are tabulated as shown in table 19. The quantities as taken from the mass diagram for each haul are summarized and entered in the first column of the table, with the corresponding haul distance given in the second column. On the project analyzed much material was to be hauled less than 500 feet, but the shorter hauls were all sum-

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For a brief discussion of the mass diagram and a method of taking off the quantities to be hauled any given distance, see PUBLIC ROADS, March 1928, pp. 18 and 19.

marized under this distance since it was clear that any possible minimum equipment for this job would be more than that required to keep the shovel at full production on a 500-foot haul. To further subdivide this short-haul material would only be useless labor.

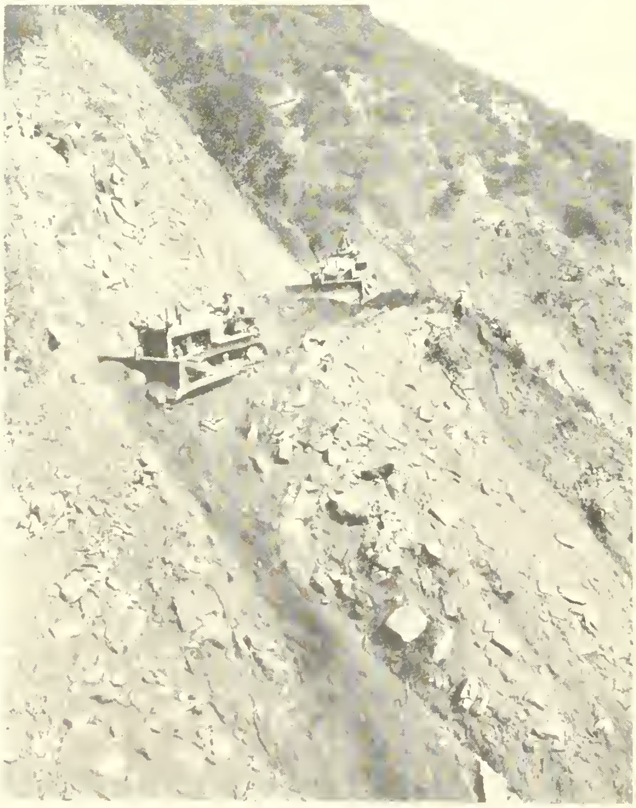
TABLE 19. *Determination of most economical number of trucks to use on a given job*

Quantities (cubic yards)[1]	Length of haul	Shovel working at full production rate		Time to complete job with—			
		Hours to complete given yardage	Number of trucks required	2 trucks	3 trucks	4 trucks	5 trucks
	Feet			*Hours*	*Hours*	*Hours*	*Hours*
14,400	500	18.00	3.00	27.00	18.00	18.00	18.00
10,800	600	13.50	3.07	20.75	13.83	13.50	13.50
7,200	700	6.00	3.24	14.58	9.72	9.00	9.00
10,800	800	13.50	3.42	23.10	15.40	13.50	13.50
15,760	900	19.70	3.44	33.90	22.58	19.70	19.70
7,200	1,100	9.00	3.76	16.92	11.28	9.00	9.00
18,400	1,500	23.00	4.00	46.00	30.70	23.00	23.00
12,800	3,000	16.00	4.67	37.40	25.00	18.70	16.00
10,600	4,000	13.25	5.55	36.80	24.50	18.41	14.70
Hours required to complete job		134.95		256.45	171.01	142.81	136.40
Estimated cost of complete job, dollars				4,103.20	3,249.19	3,141.82	3,410.00

[1] Total, 107,960 cubic yards.

This example is based on a 1¼-yard shovel operating in common excavation at a rate of 80 cubic yards per working hour. Cost of equipment and personnel on shovel, dump, and maintaining hauling road estimated at $10 per working hour. Rental value of truck and driver, $3 per working hour. For truck operation on the job the following values were used: $T=5.0$ minutes; $t=2.5$ minutes, while since the grades were not bad and a patrol grader was available for maintenance, S was taken as 400 feet per minute for all hauls to and including 500 feet; 450 feet per minute for the hauls above 800 feet to and including 1,100 feet; 600 feet per minute for all hauls of 3,000 feet or more.

If trucks could be employed and discharged in conformity with the fluctuations in the length of haul, the cost of completing the job could be reduced to about $2,900



BULLDOZERS CAN OFTEN BE USED IN OPENING THE CUT AND PREPARING A HAULING ROAD AHEAD OF THE SHOVEL.

In the third column was entered the number of hours estimated as required to move the quantities shown in the first column with a full supply of hauling equipment; in other words, the time required for the shovel to handle these quantities when working at full production. In estimating the production rate for the shovel the contractor should consider his past experience and all available evidence in regard to the character of the material and the probable conditions under which the work will be performed. If different classes of material resulting in different production rates are involved, such as common excavation, loose rock, and solid rock, the known or probable quantities of each should be entered in column 1 for each haul distance. This will result in a more reliable estimate of the time required to complete the work at each haul distance.

In the fourth column was entered opposite each haul distance and corresponding quantity the number of hauling units which would probably be necessary to maintain the shovel at full production at this haul distance. Numbers of trucks are computed with formula 2, using values for T, t, and S based on experience and judgment. The indicated number of vehicles will, in general, be a mixed number and should be entered to at least one decimal place. Two places are used in this example.

There was then entered in the following columns the time in hours required to complete each set of quantities with the number of trucks indicated. Whenever the number of hauling units is equal to or greater than that required to maintain the shovel at full production, the time required to perform the work will be determined by the shovel. When the number of hauling units is less than that required to maintain the shovel at full production, the time will be determined by the hauling equipment. This new or increased time figure will have the same ratio to the time required for completion, as given in column 3, as the required number of hauling units, as given in column 4, has to the number of hauling units which is actually to be used. The computations are simple and can be made quickly on the slide rule. The column totals give the number of hours that will be required to complete the job, when hauling equipment is supplied to the shovel exactly as needed (column 3), and when each of the assumed hauling supplies is employed continuously with the shovel until the job is completed. In this example all hauling units have been assumed to be of the same size and speed. If vehicles of different sizes and speeds are to be used the computations are more extended.

The final step in making this table was to compute the operating cost when each of the assumed hauling supplies was used for the corresponding period required to complete the job. In accordance with general experience it was assumed that the hourly rental value of the shovel and the equipment on the dump would be practically constant, regardless of the average rate of production within the limits of this particular job. The same assumption was made with regard to the personnel employed with the shovel and on the dump. The total cost per operating hour of the equipment and personnel at the shovel and dump was then estimated for the conditions which would most probably exist on the proposed job. To this was added the estimated hourly or daily rental value of the given number of hauling units with their drivers. In computing table

19, the estimated operating cost of shovel and dump was assumed for purposes of illustration at $10 per hour. The hauling equipment was assumed as heavy trucks at $3 per hour with driver. The hourly cost of operation is therefore $16 when using only 2 trucks and $25 per hour when using 5 trucks.

Completing the indicated multiplications, we find that it would cost the contractor $3,141 to complete the job with 4 trucks. Any other number of trucks, if kept out on the job throughout, would result in a higher cost. However, if trucks could have been employed and paid for only during such time as they were needed to keep the shovel at full capacity, the cost of completing the job would have been but slightly more than $2,900. The variable haul distances increased the cost of the earthwork on this job by at least $240, or nearly 8 percent—an item worth consideration by both the contractor and the designing engineer.

Occasionally the extreme hauls are localized to a certain portion of the job. In such cases the project should be divided into sections and a solution made for each. Having determined the most economical number of trucks for each section, the contractor can plan to increase or decrease the number of hauling units by the determined number when the proper points are reached.

STANDARDIZATION OF EQUIPMENT AIDS EFFICIENCY

The use of a variety of different kinds of equipment has a tendency to increase time losses and decrease production. Equipment is subjected to extremely hard usage and mechanical troubles invariably occur from time to time. It is much cheaper and less difficult to keep an adequate supply of spare parts on hand when the equipment is closely standardized than when a variety of different kinds and sizes of equipment is used. Standardization of hauling units permits interchange of parts and one line of spare parts will suffice for all the hauling equipment. If more than one shovel is employed, there is the same advantage in having them alike. This will permit not only the carrying of a smaller investment in repair parts but operators can be shifted from one piece of equipment to another without impairment of efficiency. Repair men will become more expert in making repairs as well as in diagnosing trouble and in the routine care of the equipment.

Equipment earns no profit except when working. Anything which helps to keep and continue the equipment in working order is therefore of definite value to the contractor. Standardization of equipment so as to permit a wide interchangeability of parts usually requires no outlay and only a little definite planning and forethought, and should be embraced by all contractors to whatever extent their lines of work will permit.

The most striking fact brought out by these studies is that power-shovel grading work is more a problem of transportation than of excavation. If the hauling equipment is insufficient or is not operated with precision, the shovel is handicapped, production is relatively low, and unit costs are high. On the other hand, if too many hauling units are used, unit production costs are unnecessarily increased while the problem of proper operation of the hauling units still remains. Therefore control and operation of the hauling equipment requires the constant and most painstaking attention of the management.

This attention to the hauling should not be given at the expense of an almost equally vigilant attention to all other parts of the job. The contractor can never afford to forget that the shovel is the key item of equipment. It must be constantly maintained in proper condition and operated with a high degree of skill and judgment. Operations on the dump must not be allowed to hamper or interfere with the rapid and orderly movement of the hauling units. If the ground is too hard to dig readily, drilling and blasting must also be carried on with efficiency and dispatch.

But, even all this is not sufficient. Real efficiency is attained only when all operations are performed efficiently and at the same time so coordinated and synchronized that all of these several operations proceed methodically and without interference as a definite part of one single process. To attain such a degree of efficiency in power-shovel grading work requires the constant attention of managerial ability of the highest order. However, the rewards to be gained from such management are such that no grading contractor can afford to be without it.

MOTOR-VEHICLE REGISTRATIONS, 1933[1]

[Compiled from reports of State authorities]

State	1933 registered motor vehicles—private and commercial[2]					Other registered vehicles		Tax-exempt official motor vehicles and motorcycles[3]			Licenses, permits, and certificates of title			1932 total registered motor cars, busses, and trucks (revised)[11]	Year's change in motor vehicle registration		State
	Grand total registered motor cars, busses, and trucks	Total passenger vehicles, cars, and busses[4]	Private passenger cars[5]	Public passenger vehicles[6]	Total freight vehicles, trucks, and tractors[4]	Trailers and semi-trailers[7]	Motor-cycles	United States cars, etc.[8]	State and local vehicles[9]	Motor-cycles (official)	Dealer's licenses	Operators and chauffeurs permits	Certificates of title[10]		Number	Percent	
Alabama	206,361	176,523	175,483	1,040	29,838	4,007	551	403	975	16	1,765	1,285	(12)	225,846	−19,485	−8.63	Alabama.
Arizona	89,496	71,927			14,569	1,989	293	672	1,541	23	145	10,312	38,003	94,935	−5,439	−5.73	Arizona.
Arkansas	188,242	155,262			32,980	6,887	356	297	[11] 450		[11] 306	3,346		136,583	51,659	37.82	Arkansas.
California	1,958,807	1,738,720			220,087	69,987	8,134	2,502	34,565	924	3,043	590,047		1,974,932	−16,125	−.82	California.
Colorado	266,491	239,058			27,433	832	788	521	(13)	(16)	[11] 527	17,262	96,243	286,211	−19,720	−6.89	Colorado.
Connecticut	314,751	262,187			52,564	1,816	1,985	733	2,910	240	2,232	413,538	(12)	321,580	−6,829	−2.12	Connecticut.
Delaware	51,099	[14] 42,614			[14] 8,485	912	318	149	493	91	512	69,149	23,345	52,341	−1,242	−2.37	Delaware
Florida	279,265	234,246			45,019	9,567	834	596	3,365		2,802	2,731	96,851	286,021	−6,756	−2.36	Florida.
Georgia	330,147	278,935			51,212	5,836	956	698	(13)	(13)	1,883	5,091	1,026	287,716	42,431	14.75	Georgia.
Idaho	96,255	81,371	81,282	89	14,884	10,039	286	263	1,156	5	237	254	(15)	96,039	216	.22	Idaho.
Illinois	1,463,050	[14] 1,276,864			[14] 186,186	9,228	4,959	1,810	(16)	(16)	2,922	66,559		1,489,147	−26,097	−1.75	Illinois.
Indiana	770,071	653,710	652,800	910	116,361	27,996	2,561	589	(13)	(13)	2,265	894,939	251,057	797,126	−27,055	−3.39	Indiana.
Iowa	632,292	562,802			69,490	2,416	1,671	424	4,389	48	[11] 1,565	72,732		682,905	−50,613	−7.41	Iowa.
Kansas	517,987	[14] 445,583			[14] 72,404	3,847	709	338	[11] 4,000		1,153	43,934		504,784	13,203	2.62	Kansas.
Kentucky	294,547	262,436	261,006	[17] 1,430	[18] 32,111	(18)	822	466	2,914	67	678	8,077	(12)	291,309	3,238	1.11	Kentucky.
Louisiana	232,688	190,681	189,058	1,623	42,007	6,957	712	450	3,698	66	333	21,279		238,877	−6,189	−2.59	Louisiana.
Maine	168,173	132,902	131,765	[19] 1,137	35,271	5,893	1,001	229	1,960	92	1,106	215,553	(12)	171,424	−3,251	−1.90	Maine.
Maryland	313,274	278,546			34,728	1,383	1,185	1,018	[11] 1,400		5,228	71,732	224,362	322,106	−8,832	−2.74	Maryland.
Massachusetts	789,788	689,934	686,249	3,685	99,854	525	948	1,301	2,800	[11] 500	2,753	1,022,662	(12)	801,317	−11,529	−1.44	Massachusetts.
Michigan	1,077,209	[14] 955,570			[14] 121,639	78,998	2,914	866	(13)		1,384	266,391	418,226	1,136,224	−59,015	−5.19	Michigan.
Minnesota	679,243	580,113	579,908	205	99,130	19,648	1,687	644	3,109	78	872	48,867	1,140	682,953	−3,710	−.54	Minnesota.
Mississippi	164,688	131,764			32,924	850	199	262	[11] 2,000		[11] 428			153,741	10,947	7.12	Mississippi.
Missouri	698,362	[14] 594,567			[14] 103,795	13,110	1,492	842	2,252	21	1,622	38,399	265,600	717,460	−19,098	−2.66	Missouri.
Montana	110,245	[14] 82,765			[14] 27,480	483	272	631	[11] 1,300		433	223	12,324	109,203	1,042	.95	Montana.
Nebraska	390,651	336,704	336,437	267	53,947	14,727	988	278	1,488		[11] 3,795	472,324	11,522	374,849	15,802	4.22	Nebraska.
Nevada	28,324	22,397			5,927	631	92	116	551		70			31,378	−3,054	−9.73	Nevada.
New Hampshire	107,631	87,759	87,492	[20] 267	19,872	1,922	1,102	231	61	2	[11] 416	[11] 129,750		105,215	2,416	2.30	New Hampshire
New Jersey	845,734	723,506	714,358	[21] 9,148	122,228	3,162	5,268	872	8,901	787	2,427	1,043,185	[22] 200,000	854,782	−9,048	−1.06	New Jersey.
New Mexico	76,643	61,353	61,065	288	15,290	983	263	410	839		84			76,872	−229	−.30	New Mexico.
New York	2,240,757	1,942,249	1,905,733	[23] 36,516	[24] 298,508	13,515	12,723	3,048	21,609	1,063	4,955	3,201,357		2,249,509	−8,752	−.39	New York.
North Carolina	382,308	332,648	327,816	4,832	49,660	13,012	1,151	563	8,878		[11] 573		193,192	376,326	5,982	1.59	North Carolina.
North Dakota	153,889	[14] 128,547			[14] 25,342	143	204	181	453		283		31,373	153,232	657	.43	North Dakota.
Ohio	1,554,314	[14] 1,396,125			[14] 158,189	61,156	5,940	1,664	14,074	353	3,131	26,240		1,589,322	−35,008	−2.20	Ohio.
Oklahoma	451,712	385,755			65,957	4,184	[11] 700	742	[11] 2,000		[11] 1,200			415,644	36,068	8.68	Oklahoma.
Oregon[25]	239,410	207,202	[26] 206,502	[27] 700	[28] 32,208	[29] 1,750	1,421	538	3,204		322	106,503	84,398	258,762	−19,352	−7.48	Oregon.
Pennsylvania	1,635,019	1,415,522	1,409,708	[30] 5,814	219,497	10,139	11,436	1,816	15,589	1,315	23,718	2,112,195	881,133	1,665,418	−30,399	−1.83	Pennsylvania.
Rhode Island	136,261	118,296	117,161	[31] 1,135	17,965	92	882	189	1,141	72	273	170,509		133,408	2,853	2.14	Rhode Island.
South Carolina[32]	162,735	144,940	144,794	146	17,795	1,764	444	290	2,721	157	[11] 426	259,535	69,464	176,370	−13,635	−7.73	South Carolina.
South Dakota	169,249	146,485	146,408	77	22,764	9,693	287	342	922	10	[11] 364		28,000	162,096	7,153	4.41	South Dakota.
Tennessee	312,180	278,332	276,762	[33] 1,570	33,848	2,982	1,064	415	2,500		[11] 398			298,713	13,467	4.51	Tennessee.
Texas	1,201,762	1,013,086	1,012,415	671	188,676	36,073	3,355	1,729	8,530	232	[11] 2,440	[11] 56,730		1,197,443	4,319	.36	Texas.
Utah	100,362	84,014			16,348	457	447	428	900		147	30,283	9,028	97,234	3,128	3.22	Utah.
Vermont	73,576	65,652	65,531	121	7,924	683	553	138	[11] 400		272	92,675		77,475	−3,899	−5.03	Vermont.
Virginia	344,704	288,048	285,497	2,551	56,656	1,845	1,756	1,366	4,295	61	[11] 2,300	[11] 12,077	144,314	376,512	−31,808	−8.45	Virginia.
Washington	427,406	364,858	363,706	[34] 1,152	62,548	4,849	1,629	1,220	6,786	175	966	410,860	240,838	445,314	−17,908	−4.02	Washington.
West Virginia	226,985	193,570	192,393	[35] 1,177	33,415	2,094	1,164	162	3,064	90	5,645	69,218	96,305	225,137	1,848	.82	West Virginia.
Wisconsin	670,797	566,450	566,045	405	104,347	2,565	2,256	514	5,817	297	1,574	60,517	14,941	695,953	−25,156	−3.61	Wisconsin.
Wyoming	52,560	41,917			10,643	[11] 20	121	332	473		278			56,209	−3,649	−6.49	Wyoming.
District of Columbia	149,790	133,048	125,373	[36] 7,675	16,742	1,112	808	1,854	2,789	110	2,253	76,444	70,677	161,176	−11,386	−7.06	District of Columbia.
Total	23,827,290	20,600,543	(37)	(37)	3,226,747	472,789	91,987	[8] 36,475	193,262	6,895	94,504	12,214,764	3,503,362	24,115,129	−287,839	−1.19	Total.

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[1] This table lists only the number of registrations, licenses, and permits.

[2] The first 5 columns show regularly registered motor cars, busses, and trucks, with reregistrations, nonresident registrations, tax-exempt vehicles, etc., eliminated whenever possible.

[3] These official cars are exempted from paying regular registration fees and are excluded from "registered motor vehicles."

[4] In certain States noted below busses are registered as trucks and are included in the truck registration.

[5] Data shown here only where private passenger cars can be segregated from public passenger vehicles.

[6] Satisfactory data have not been obtained from several States. These data may include such vehicles for hire as taxis, U-Drive-It cars, livery cars, ambulances, hearses, and busses (not tax-exempt), where the information is obtainable. In most cases only busses are reported in this column, but in certain States the number of taxis, etc., are reported and are so noted.

[7] No segregation is made as between freight and passenger trailers.

[8] As reported by the Budget Bureau in 1931 The total includes 333 cars "at-large" not assignable to any State.

[9] Official cars which are exempt from full fees.

[10] Both original certificates and transfers are shown.

[11] Revised figures resulting from the 1932 special survey.

[12] None issued.

[13] Included with registered motor vehicles as full fees are paid.

[14] Busses reported as registered with trucks and are so included.

[15] No record of number issued as no charge is made.

[16] Nominal fee paid on official vehicles and they are included with registered motor vehicles.

[17] Includes 1,024 taxis.

[18] Trailers included with trucks.

[19] Includes 1,016 taxis.

[20] Includes 6 snowmobiles.

[21] Includes 4,286 taxis.

[22] Number of title papers recorded from bills of sale; no certificates issued.

[23] Includes approximately 30,516 taxis.

[24] Includes 7,720 suburban convertible cars.

[25] Data covers registration year ending June 30, 1933

[26] Excludes 11,700 light-delivery cars as estimated from data of previous year and reported by State as passenger cars.

[27] Includes 309 taxis.

[28] Includes 11,700 light-delivery cars, and excludes 1,750 trailers (estimated) reported with trucks by State.

[29] Approximate number estimated from data for previous year.

[30] Busses only reported; approximately 3,000 taxis not reported with public passenger vehicles.

[31] Includes 632 taxis.

[32] Data covers only 10 months as registration year was changed from calendar year to year ending Oct. 31.

[33] Includes 1,220 taxis.

[34] Includes 581 taxis.

[35] Includes 692 taxis.

[36] Includes 6,879 taxis.

[37] Total not recorded, as only about one-half of States reported segregated data under public passenger cars.

STATE MOTOR VEHICLE REGISTRATION FEES, 1933

[And miscellaneous receipts (excluding special for-hire carrier taxes and fees)] [1]

State	Total receipts registration fees, and miscellaneous receipts	Motor vehicle registration fees					Registration fees, other vehicles		Miscellaneous receipts					Disposition of total receipts					
		Total motor vehicle registration fees [2]	Passenger vehicles			Total trucks and tractor trucks [6]	Trailers and semi-trailers [7]	Motorcycles [8]	Total	Dealers licenses and plates	Operator and chauffeur permits	Certificates of title	Other miscellaneous items	Collection and administration [10]	For construction and maintenance of		State and county road bond payments [11]	For city streets	For other purposes
			Total [3]	Private cars [4]	Public vehicles [5]										State highways	Local roads			
Alabama	$2,724,257	$2,676,873	[3] $2,096,223			[6] $580,650	[7] $35,620	[8] $2,200	$9,564	$1,765	$6,425		$1,374	$141,215	$987,359	$531,230	$1,064,453		
Arizona	647,816	534,044	276,478			257,566	24,017	1,029	88,696	1,165	12,435	$38,003	37,093	171,906	475,910				
Arkansas	1,768,850	1,622,457	[3] 1,165,907			[6] 456,550	[7] 114,050	[8] 4,020	28,323	6,080	16,732		5,511	[12] 76,369	1,069,042		623,439		
California	9,866,449	[2] 8,572,540	[2] 5,926,481			[2] 2,646,059	[2] 540,449	28,449	725,011	32,701	66,470	(13)	125,840	1,722,860	2,901,802	2,901,802	27,033		[14] $2,312,952
Colorado	2,035,608	1,554,751	1,208,768			345,986	11,979	1,434	467,441	16,480	35,796	96,243	318,922	138,730	601,357	609,765	145,000		[15] 537,756
Connecticut	7,850,589	5,936,579	4,481,119			1,455,460	40,183	8,940	1,864,887	76,005	1,247,944		540,938	[16] 1,017,681	6,832,908				
Delaware	1,011,333	857,576	612,844		(17)	244,732	10,619	1,063	145,075	5,840	104,838	27,629	6,768		799,182		[18] 215,151		
Florida	4,994,882	4,788,921	3,695,537			1,093,387	53,797	5,649	146,512	12,580	4,428	99,805	29,699	395,724					[19] 4,599,158
Georgia	1,036,211	989,092	835,669			153,423	17,893	2,869	26,387	5,646	10,174	513	10,054	137,716	898,525				
Idaho	1,401,819	1,360,553	1,017,410	$999,888	$17,522	343,143	15,053	1,427	24,816	14,220	508	(13)	10,088	104,659	124,590	1,172,600			
Illinois	16,229,327	15,514,150	11,685,116		(17)	3,859,334	120,803	14,606	549,468	48,688	210,981		289,799	[20] 272,127	5,598,990	1,030,235	8,249,560	$221,277	[21] 857,138
Indiana	7,816,883	6,922,464	3,905,707	3,833,609	72,098	3,016,757	153,341	5,122	765,956	45,300	417,469	125,529	147,658	268,851	3,789,016	1,515,606		378,902	[22] 1,894,508
Iowa	10,695,407	10,319,082	8,612,322			1,676,760	35,837	6,467	334,021	42,931	47,238		243,852	[23] 431,837	9,905,148				[24] 355,422
Kansas	3,056,837	2,939,865	2,227,915		(17)	[6] 711,950	[7] 26,930	[8] 3,332	86,710	19,376	20,855		46,479	198,699	1,058,138	1,800,000			
Kentucky	4,174,076	4,052,388	2,919,066	2,864,233	54,833	[6] 1,133,322	(25)	3,117	118,571	19,224	15,227		84,120	235,953	3,387,049	551,071			
Louisiana	4,052,816	3,691,661	2,832,173	2,770,824	61,349	859,488	273,256	4,191	83,708	12,220	63,837		7,651	130,264	3,602,252		320,300		
Maine	2,909,237	2,326,367	1,691,812			[6] 634,525	9,161	5,288	568,418	42,690	457,673		68,055	489,906	514,919		1,904,412		
Maryland	3,581,251	2,733,461	[2] 2,286,089			[2] 447,375	54,470	7,258	786,059	30,013	189,450	224,363	342,233	559,108	2,115,500			906,643	
Massachusetts	6,508,313	3,707,822	2,517,166	2,128,076	9,090	1,188,656	30,711	1,394	2,770,386	62,250	2,045,118		663,018	1,511,678	2,401,781	761,125	[18] 130,022	613,360	[26] 1,087,377
Michigan	18,560,314	17,002,776	13,344,020		(17)	3,658,756	491,638	10,359	1,055,541	53,260	318,192	418,226	265,563	793,502	10,144,796	6,000,000	1,082,060		[27] 539,956
Minnesota	6,366,982	6,196,749	4,682,934	4,588,857	93,177	1,514,715	66,491	5,450	98,289	21,480	54,016	285	19,508	298,176	2,805,476		[28] 2,825,082		[29] 438,248
Mississippi	1,870,396	1,823,179	1,317,640			[6] 505,539	[7] 15,700	[8] 2,040	29,477	1,588			27,889	99,606	102,638	1,668,152			
Missouri	9,356,828	8,715,460	[3] 7,676,372		(17)	[6] 1,069,088	[7] 42,800	[8] 7,040	561,528	46,809	115,197	265,600	133,922	331,322	1,590,906		7,434,600		
Montana	1,070,104	1,017,780	821,758		(17)	196,022	1,139	525	50,860	11,456	446	12,324	23,634	42,636		1,027,468			
Nebraska	1,721,831	1,599,853	1,097,162	1,082,488	14,674	502,691	21,630	1,584	98,767	11,588	13,568	11,436	62,175	71,761	495,022	1,155,051			
Nevada	299,634	287,920	198,041			89,879	3,311	349	8,024	2,318	(13)		5,706	43,087	81,297		175,250		
New Hampshire	2,167,421	1,764,161	1,151,031			[6] 610,130	[7] 23,000	5,299	374,961	21,147	283,306		70,508	97,554	2,069,867				
New Jersey	15,377,813	11,055,464	7,179,943	7,129,422	350,521	3,575,521	121,267	10,536	4,190,576	60,485	3,119,621	340,094	670,376	[30] 1,547,702	2,500,000	7,200,330	[31] 2,586,022		[32] 1,543,789
New Mexico	666,718	628,681	410,841	396,254	14,587	217,810	8,238	549	29,280	4,241		(13)	25,069	93,027	286,861	93,011			[33] 193,849
New York	42,318,107	37,713,329	26,241,861	25,470,431	771,430	11,471,468	315,235	46,213	1,243,630	197,445	2,911,781		1,134,404	[34] 3,396,003	8,475,142	5,764,872		3,885,805	[22] 20,796,585
North Carolina	5,356,126	4,915,234	4,107,366	3,908,445	198,921	807,868	313,660	4,260	122,972	17,498		96,596	8,878	[35] 179,335	[36] 1,247,480	1,193,852	[37] 2,676,848		[21] 58,611
North Dakota	1,382,008	1,338,366	1,025,561		(17)	312,802	1,388	1,226	41,028	7,795		31,373	1,860	[38] 92,564	14,554	174,890			[39] 1,100,000
Ohio	17,677,551	16,825,662	11,363,217		(17)	5,462,445	462,989	23,579	365,321	89,082	78,047		198,192	505,557	3,804,967	10,014,087		3,352,940	
Oklahoma	3,382,455	3,319,917	2,700,287			[6] 619,630	[7] 41,840	[8] 5,700	15,000	15,000				171,727	1,281,896	1,753,470		169,374	[22] 5,988
Oregon	5,337,137	5,092,302	4,081,122	4,033,280	47,842	1,011,180	32,550	5,061	207,224	24,707	64,896	81,398	33,223	282,668	2,069,429	1,148,637	1,548,769		[41] 287,634
Pennsylvania	29,181,792	21,587,486	14,814,281	14,289,453	524,828	6,773,205	149,392	26,979	7,420,935	289,745	4,368,174	1,123,594	1,639,422	3,881,577	16,988,326	(42)	3,487,583		[43] 4,827,306
Rhode Island	2,198,312	1,755,483	1,333,257	1,266,595	66,662	422,226	1,528	3,189	438,142	13,230	339,504		85,408	292,399	852,744	53,199			[44] 1,000,000
South Carolina	2,503,367	2,142,015	1,710,109			[2] 401,906	[2] 56,572	1,810	302,970	20,251	153,473	34,732	94,514	69,231	437,214		[46] 1,698,365		[47] 298,557
South Dakota	1,459,027	1,410,321	1,244,155	1,241,940	2,215	166,166	11,550	335	36,821	8,970		16,383	11,468	52,773	282,746	1,123,508			
Tennessee	2,910,010	2,824,327	2,365,822			[6] 458,505	[7] 43,239	[8] 4,256	68,188	15,721			52,467	120,617	1,336,720	1,336,720			[41] 145,953
Texas	12,717,489	12,019,908	8,410,082	8,336,031	74,051	3,609,826	260,235	13,426	453,920	31,290	170,190		252,440	632,834	3,898,417	8,246,238			
Utah	797,598	749,159	553,942			195,217	6,223	938	41,278	5,952	10,470	9,027	15,829	60,098			737,500		
Vermont	2,072,717	1,787,170	1,388,813	1,373,522	15,291	398,357	2,951	3,351	279,245	26,143	223,796		29,006	112,203	1,438,064	270,000	252,450		
Virginia	6,090,279	5,756,627	4,694,216	4,614,359	79,857	1,062,411	19,500	7,826	306,326	39,484	62,509	144,315	60,018	615,120	5,475,159				
Washington	2,482,758	1,870,765	1,106,621	1,059,592	47,032	714,141	50,486	4,286	577,221	15,344	418,650	136,798	6,429	409,480	1,401,114	510,594		13,670	[48] 147,900
West Virginia	3,837,922	3,523,186	2,723,231	2,612,751	110,480	799,955	9,678	4,330	300,728	27,083	109,493	96,306	67,846	148,988			3,688,931		
Wisconsin	9,768,006	9,455,019	7,137,743	6,941,281	196,462	2,317,276	153,900	11,169	147,918	6,594	15,129	3,735	122,460	767,591	4,008,995	2,213,251	[49] 1,339,657	343,835	[50] 1,094,671
Wyoming	679,411	666,932	471,413			195,519	[7] 500	[8] 525	11,454	7,244			4,210	13,571	499,857		166,000		
District of Columbia	627,708	155,971	132,818	125,143	7,675	22,853	1,112	808	167,617	2,253	240,926	70,677	153,761	85,238				540,270	
Total	302,404,967	266,139,886	195,841,626	(4)	(4)	70,298,260	1,298,007	320,853	31,935,250	1,596,047	18,075,282	3,507,984	8,755,337	23,316,236	120,656,135	61,793,770	42,378,490	10,426,076	[illegible]

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[1] Financial data only on this table.

[2] Only registration fees are shown, except that in States as noted certain special taxes are paid in lieu of registration fees and in such cases the special taxes are here included.

[3] Reports from certain States do not segregate passenger vehicle fees. In such cases approximations have been made as noted.

[4] Many States do not segregate public vehicles for hire from privately owned passenger cars and returns are therefore incomplete.

[5] Includes all passenger vehicles for hire such as taxis, U Drive-It cars, livery cars, busses, ambulances, and hearses, if so classed by the State registration agency. Some States class busses with trucks and such cases are noted.

[6] Certain States do not segregate truck registration and in such cases approximations have been made as noted.

[7] Approximations have been made as noted.

[8] Approximation based on 1932 special survey.

[9] A new column has been added and headed "for city streets"; data were formerly under "other purposes."

[10] Some States pay part or whole of administration expenses from State appropriation and such cases are noted.

[11] Payments on State highway bond obligations, except as noted.

[12] Includes extra amount for special auditing.

(Footnotes continued on following page.)

[13] No fees charged.

[14] Includes $1,681,002 for State motor police, and $631,950 for motor-vehicle reserve fund.

[15] Includes $109,381 for State general fund diverted from State highway fund; $288,785 from extra $1 assessment on each motor vehicle registered and credited to county pension funds; and $139,590 diverted from county road fund for police pension fund.

[16] Includes refunds of $201,094.

[17] Bus fees included with truck fees.

[18] Bond payments from combined fund of gasoline taxes and motor-vehicle fees and are prorated between them.

[19] For county school fund.

[20] For 6-month period.

[21] For State highway patrol.

[22] For State general fund.

[23] Includes $106,482 to counties for refunds.

[24] Includes $21,614 for State general fund and $333,808 to county funds.

[25] Trailers classed with trucks and not separable.

[26] Includes $605,861 to State general fund, which amount with the amount allocated from gasoline taxes, make the total $8,028,320 for unemployment relief; for State police expenses, $296,900; and the remainder for miscellaneous nonroad purposes.

[27] Includes $221,464 for highway police, and $318,492 to State general fund.

[28] Includes $1,481,832 payments on county bonds.

[29] To State general fund, $360,000.

[30] Includes $1,188,430 for administration formerly paid by State appropriation.

[31] Repayment of loan.

[32] Includes $175,000 to free bridge commission, $400,000 for Bayonne bridge, and $968,789 in closed banks and not assignable.

[33] Includes $95,620 to State general fund and $98,229 to county funds.

[34] Excludes $1,291,458 paid from State general fund; includes $2,491,684 refunds of surtax paid (pursuant laws 1932) and refunded (pursuant laws 1933); remainder county clerk fees.

[35] Includes $96,596 from certificate of title fees for auto-theft prevention and recovery fund.

[36] Includes $664,544 which it is anticipated will be appropriated for State highways

[37] Includes $147,056 county loan repayment.

[38] Includes $56,057 rebates for overcharges, due to reduction in fees.

[39] Transfer to real estate bond payment fund, not used for highway purposes.

[40] Covers registration year ending June 30, 1933.

[41] Light delivery trucks reported by State as passenger vehicles. Estimated fees for these trucks deducted from passenger cars and added to trucks.

[42] Included with State highway funds, not reported separately.

[43] Includes $4,042,235 paid on State debt obligations, $624,554 for highway patrol, $87,555 for State employees' retirement board, and remainder for miscellaneous expenses.

[44] For relief aid to cities and towns.

[45] Data covers 10 months to Oct. 31 due to change in registration year.

[46] Includes $1,273,939 payments on county bonds.

[47] Includes $213,919 for State highway patrol, and remainder for operating expenses of motor transport division of railroad commission.

[48] Excludes refunds on licenses of $463,024 due to reduction of registration fees.

[49] Payments on county road bonds.

[50] Allotment to counties in lieu of personal property taxes on motor vehicles, used to lower county taxes.

[51] Includes $75,473 for street signals; the remainder for streets as appropriated by Congress.

[52] Total not shown as less than half the States do not segregate private and public vehicles.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF AUGUST 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$4,123.000	$2,129.921	$2.359.732	$1.305.902		100.4	$4,167.871	$2.339.025	—	253.7	$238.941		29.1	$239.132	$2.129.921
Arizona	3.878,555	1.338,712	2,468.228	2,421.498		176.1	1.990.270	1.424.949		118.9				32,108	1.338.712
Arkansas	3.374.167		954.076	828.012		31.5	2.662.979	2.244.432		137.1	189.489		5.1	112.234	
California	7.912,928	3,966.103	4.736,362	3.559.590		175.6	6.501.997	4.229.795		139.5				123.543	3.966.103
Colorado	3.437.265	1,743.003	2.432,060	2.411.800		119.5	1.114.321	985.753		31.4		$239.657	19.0	39,712	1,503.346
Connecticut	1.404,213	607.500	189.823	189.823		3.0	1.385,153	1.213.805		27.8	584				607,500
Delaware	909,544	461,697	319.586	317.492		7.3	564,607	564.607		10.7		387.793	14.4	27,446	73.904
Florida	2.519.010	1.330.671	2,532,194	1.857.220		86.1	676.287	564.997		29.9	20.185		.6	76,608	1.330.671
Georgia	5.045,592	2,556.745	1.904.552	1,892,583		123.4	2.254.580	2,239.606		153.0	183.266		10.4	730,138	2,556.745
Idaho	2,166.858	1.131.910	1.132,998	1.089.288		123.1	984.108	966.211		52.3	5.180	110.022	10.8	106.179	1.021,888
Illinois	4,585.971	3.060.041	582,802	582.136		14.3	3,348,871	3.348.871		37.7	563.160		5.3	91.804	3,060,041
Indiana	5.018.921		589.079	589.079		25.5	3.792.054	3.792.054		99.3	371.531		14.0	266.258	
Iowa	5.027.830	2,217,361	2,166.551	2.086,800		125.8	3.161.917	2,920.430		143.3		58,780	34.7	20.600	2,158,581
Kansas	5.044,802	2,558,837	3.041.582	3.037.735		330.3	2.264,672	1.990.590		67.5	16.476	6.562	4.2		2.552.275
Kentucky	3.751,605	1.527,324	2,042,206	2.026,751		160.3	1.535,000	1.375.661		85.1	307.268		9.0	41.926	1.527.324
Louisiana	2.914.295		742,275	741.041		29.3	2.413.992	1.907.341		48.6	23.133		.7	242.780	
Maine	1.617.560	793.644	671.109	665,698		25.2	876.580	846.424		18.9				105.438	793.644
Maryland	1.782,263	289.610	156.306	146.657		4.8	948.030	948.030		16.5	632.827	124,112	13.8	54,749	165.498
Massachusetts	1.101.716		679.177	496,986		18.9	738,165	527,406		18.9				77.325	
Michigan	6.113.389	3,226,284	1,046.200	1.046,200		45.4	4,824,725	4.775.725		222.7	39.600			251.864	3,226,284
Minnesota	4,561,011	2.642,244	2,969.881	2,932.318		604.5	1,649.485	1.620,921		161.8	7.772				2.642.244
Mississippi	3.489,337	2.301.148	1,324,173	692,326		68.9	3,887.867	2.138,327		204.4	279.537		33.4	379.147	2.301.148
Missouri	5.237.532	2.778.183	1.687.001	1.369.015		75.5	3.761.252	3.532.726		126.8	142,147	513.117	24.0	193.644	2,265.066
Montana	4,463,849	2.714,208	3.501.615	3.315.066		273.1	1.645,007	1.138.661		127.7				10.122	2,714.208
Nebraska	3.914.481	1.982.182	3.195.168	2.459,984		265.4	1.892.738	1,452,821		96.2	1.676		1.2		1,982,182
Nevada	2.909.387	1.350.356	1.786,345	1.786.345		199.3	1.154.132	1.107.183		65.5	15.000	123.035	8.9	859	1.227.321
New Hampshire	725.739	484.731	602.305	595.769		9.7	142.375	129.970		1.5					484.731
New Jersey	3.099.371		137.255	137.255		7.0	3.037.598	2.882.677		40.1	3.846			75.593	
New Mexico	2.846.648	1.470,850	2,380.112	2.236.182		250.7	554.324	554.324		23.5		111.645	33.8	56,142	1.359.205
New York	10.271.846	2,872,521	2.742.975	2.217.390		53.1	10,083.361	7.977.101	$163.900	197.2	23.198	2.355.000	39.9	54.158	353.621
North Carolina	4.761.147	2,420.471	1.920.481	1.463,973		176.0	2.788.751	2,553.105		432.8	268.618		23.0	475.451	2,420,471
North Dakota	2,902,224	1.469.483	2,225.649	2.078,880		800.1	933.742	677.206		175.7	114.157		44.0	31.982	1,469,483
Ohio	7.277.758	3.539.256	3,498.716	3,444,333		100.8	4,130.948	3.772.933		91.1				60.492	3.539.256
Oklahoma	4.608.399	2.342.590	2.338.452	2.312,351		164.2	1,870.419	1.870.419		133.6	168.753		6.2	256,875	2.342,590
Oregon	3.053,448	1.548.906	2.093.778	1.876.545		126.2	1.266.023	1.150,740		57.3	13.619			12.543	1.548,906
Pennsylvania	6.691.194	4.554.082	1,434.527	1.432.138		44.1	5.391.697	5.051.393		87.5	32.258			175.404	4,554,082
Rhode Island	979.367		363.973	363.973		9.5	632.057	569.189		11.0				46,204	
South Carolina	2.729.583	1.385.477	420.290	420.290		36.7	2.094.852	2.092.122		187.2	114.867		5.8	102,304	1.385,477
South Dakota	3,005.739		1,452,930	1.357.681		259.3	1,628.994	1,300.320		218.8	179.369		49.3	168,369	
Tennessee	4.246.309	2,105.453	2.381.895	1.989.973		106.7	2.186.046	2,003.234		73.6	87.790		8.4	165,312	2,105.453
Texas	11.588.643		7.146.472	6.235.064		696.0	4.690.100	4,482.502		313.4	250,502		5.2	620.575	
Utah	2,374.205	1.066,345	1.646,781	1.634.539		154.7	776.074	695,715		40.9		630.000	83.4	43.951	436.345
Vermont	928.184	466,042	220.712	218,837		13.8	727.931	698.677		31.0	10,670	31.535	3.3		434,507
Virginia	3.708,379	1.882.693	2,246,847	2,190.769		108.5	1.317.916	1.208.295		30.5	93,686		8.5	215.629	1,882,693
Washington	3.057.934	1.553.206	1,765,642	1.760.626		73.0	1,252.529	1.252.529		32.8	15.918	303.286	10.1	28,861	1,249,920
West Virginia	2.013.405	1.140.167	766,411	766.411		25.8	1.185,809	1.179.809		46.5	48.955		.1	18,230	1.140.167
Wisconsin	4,615.429	2,223.827	2,423.865	2.392.313		108.0	2,227,870	2,148,125		120.8	49.156		1.3	25,835	2.223.827
Wyoming	2,250.663	1.143,856	1,467.177	1.278,956		285.5	1,266,366	938.426	240,571	213.3	12.361	393.440	59.0	20,920	509.845
District of Columbia															
Hawaii	1.683.956		196.115	144.003		10.5	1.724.330	1,389.715		25.1	144.921		4.1	5.316	
TOTALS	185.724,651	76.377.640	87.084.441	78.395.596		6.832.4	112.106,772	96.774.877	404,471	5.080.4	4.670.416	5.387.984	624.0	5.883.762	70.585.185

NOTE: THE APPORTIONMENT AND BALANCE OF 1935 FUNDS ARE INCOMPLETE SINCE THE ASSIGNMENT OF FUNDS TO THE THREE CLASSES HAD NOT BEEN RECEIVED FROM ALL STATES ON AUGUST 31.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF AUGUST 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2.175.100	$ 1.064.961	$ 395.168	$ 395.168		9.4	$ 1.445.005	$ 1.445.005		45.6	$ 297.599		8.6	$ 37.328	$ 1.064.961
Arizona	807.982	305.191	428.304	428.304		10.3	191.147	191.147		2.7	138.121		.3	50.411	305.191
Arkansas	1.889.534		537.998	505.683		16.9	1.164.932	1.082.775		25.7	300.722		1.3	353	
California	4.213.986	1.983.052	2.594.265	2.290.546		33.1	2.262.518	1.854.388		19.6				69.051	1.983.052
Colorado	1.718.633	871.501	1.384.382	1.337.363		27.1	360.951	360.951		7.8	20.319		.2		871.501
Connecticut	802.407	426.500	455.441	455.441		5.4	349.036	345.893		4.8				1.072	426.500
Delaware	454.772	230.849	151.147	142.866		1.4	311.906	311.906		6.0		$ 48.713	.7		182.136
Florida	1.405.008	665.336	690.329	483.407		8.1	944.211	913.240		10.0	8.361		.8		665.336
Georgia	2.724.620	1.278.373	503.475	503.207		22.2	1.242.875	1.242.875		41.1	34.835		1.1	943.703	1.278.373
Idaho	1.197.829	321.126	527.716	516.119		11.3	628.416	612.538		7.0		2.643	1.3	69.173	318.483
Illinois	7.718.839	2.515.835	1.859.312	1.858.572		25.5	5.295.434	5.295.434		44.6	447.971		1.4	116.862	2.515.835
Indiana	4.416.651		419.385	417.801		11.5	2.753.981	2.753.981		53.3	881.158		8.3	363.711	
Iowa	2.815.585	1.311.000	1.086.700	1.039.245		32.6	1.064.438	1.007.670		17.1	323.600	3.420	5.7	445.070	1.307.580
Kansas	2.522.401	1.279.419	1.802.400	1.797.997		31.9	868.976	724.122		5.2	282	651	.4		1.278.768
Kentucky	1.927.828	954.578	395.648	387.265		10.2	924.875	920.648		18.2	438.496		2.9	181.419	954.578
Louisiana	1.457.148		463.626	463.626		10.1	975.697	949.104		15.9	44.418		1.0		
Maine	909.878	490.045	443.434	441.228		9.6	395.558	394.662		7.1				73.988	490.045
Maryland	891.132	452.514	16.789	12.639		.6	385.808	385.808		3.6	268.000		.4	224.685	452.514
Massachusetts	5.007.199		129.536	87.991		3.8	4.697.400	4.672.424		12.8	127.088			119.696	
Michigan	3.438.781	1.613.142	692.000	692.000		9.2	2.727.320	2.712.670		32.2	27.650			6.461	1.613.142
Minnesota	3.719.143	1.421.494	1.636.657	1.624.792		71.3	1.538.554	1.523.082		29.0	29.358		.5	541.912	1.421.494
Mississippi	1.744.669	885.057	190.463	178.003		6.4	848.185	848.185		28.8	113.733		4.5	604.748	885.057
Missouri	4.019.501	1.543.435	985.269	951.647		30.6	2.671.193	2.253.278		24.8	202.870	95.145	5.5	611.707	1.448.290
Montana	1.115.962	113.092	684.821	684.821		20.8	375.553	375.553		11.3	45.118		3.8	10.470	113.092
Nebraska	1.957.240	991.091	647.890	645.868		20.0	1.264.539	1.264.539		13.0	33.507		.2	13.327	991.091
Nevada	500.051	100.000	93.177	93.177		2.5	359.775	359.775		5.7	28.068		.6	19.031	100.000
New Hampshire	706.640	242.366	379.645	364.160		7.9	300.206	300.206		7.7				42.274	242.366
New Jersey	3.190.118		312.610	312.610		4.7	2.848.820	2.794.687		18.1				82.820	
New Mexico	1.674.158	735.425	883.746	883.746		24.6	533.981	533.981		8.5	75.947		.7	180.484	735.425
New York	8.449.487	4.203.000	1.334.673	1.334.292		17.0	7.001.468	6.480.635	$ 4.400	45.4	530.908	669.000	4.5	103.652	3.529.600
North Carolina	2.380.573	1.210.235	1.204.676	1.201.286		47.5	610.821	609.329		26.3	437.304		6.0	132.655	1.210.235
North Dakota	1.451.112	734.742	518.689	518.513		21.8	376.226	375.640		15.4	473.289		19.5	83.669	734.742
Ohio	4.335.686	2.359.503	1.882.297	1.687.401		27.8	2.979.930	2.632.467		31.6				15.817	2.359.503
Oklahoma	2.304.200	1.171.295	777.614	776.493		19.2	1.211.340	1.211.340		23.1	146.881		3.1	169.486	1.171.295
Oregon	1.526.724	774.454	575.342	558.520		13.7	860.536	859.867		14.1	30.841		.6	77.496	774.454
Pennsylvania	4.854.988	2.397.703	2.021.106	1.969.024		37.1	2.356.591	2.325.431		21.5	265.800		1.2	294.733	2.397.703
Rhode Island	579.625		306.462	306.462		5.0	234.782	234.782		2.4				38.381	
South Carolina	1.364.791	692.738	256.555	256.555		7.5	818.502	818.097		32.6	77.402		1.6	212.736	692.738
South Dakota	1.502.870		532.236	532.236		16.6	602.503	602.503		21.8	46.225		2.4	321.905	
Tennessee	2.123.155	1.121.790	974.805	974.666		15.0	639.458	639.458		8.3	387.926		4.2	121.105	1.121.790
Texas	6.642.863		2.191.753	2.060.617		74.9	3.191.482	3.168.006		37.7	945.074		5.5	469.166	
Utah	771.826	533.173	618.072	602.012		14.0	54.016	53.423		2.8		10.805	1.5	116.391	522.368
Vermont	500.509	240.611	239.815	231.472		6.8	286.368	269.037		7.8					240.611
Virginia	2.008.458	941.347	873.275	851.707		20.4	940.697	750.189		3.9	275.975		2.8	130.588	941.347
Washington	1.977.260	776.603	1.584.672	1.567.700		29.4	377.994	377.994		3.0		78.518	1.4	31.566	698.085
West Virginia	1.342.270	570.085	169.068	169.068		4.1	1.044.214	1.019.869		15.5	106.562		.9	46.772	570.085
Wisconsin	2.684.067	1.235.459	1.205.225	1.191.458		34.0	1.437.855	1.409.793		17.8				82.316	1.235.459
Wyoming	1.125.332	571.928	342.527	342.024		8.4	775.045	774.461		15.5	8.847	3.485	.7		568.443
District of Columbia	959.235	389.537	530.052	530.052		3.2	440.028	423.044		1.5		263.281	1.9	6.139	126.256
Hawaii															
TOTALS	116.007.826	41.719.585	38.930.247	37.656.850		902.4	65.971.146	63.465.892	4.400	875.2	7.620.255	1.175.661	108.0	7.264.829	40.539.524

NOTE: THE APPORTIONMENT AND BALANCE OF 1935 FUNDS ARE INCOMPLETE SINCE THE ASSIGNMENT OF FUNDS TO THE THREE CLASSES HAD NOT BEEN RECEIVED FROM ALL STATES ON AUGUST 31.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF AUGUST 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2.072.033	$ 1.064.960	$ 89.081	$ 89.081		5.7	$ 1.469.612	$ 1.469.612		109.0	$ 425.376		32.8	$ 87.964	$ 1,064,960
Arizona	525.423	998.032	114.319	114.154		7.1	418,007	406.045		35.1				5.223	998.032
Arkansas	1.484.634		61.397	61.304		26.9	1.149.455	1.149.455		120.3	10,393		1.7	263.482	
California	3.480,440	1.983.051	1,748.119	1,415.673		42.0	2.178.978	1.881.673		135.9	11,205		.7	171.589	1,983.051
Colorado	1.718.632	871.502	1.454,003	1,421.217		146.0	390.583	269.699		33.8				27.716	871,502
Connecticut	659,120	420.868					664,916	659.120		14.5					420,868
Delaware	454,772	230.849	20.825	20.825			181.855	181.855		9.1	93.632	$ 106.799	29.1	158.460	124.050
Florida	1.307.816	665.336	491.178	489.237		33.4	788.332	788.332		41.6				30,247	665.336
Georgia	2,320.973	1,278.373	485.119	485.119		37.2	744.569	744.569		66.1	325.875		21.1	765.410	1.278.373
Idaho	1.121.562	824.450	872.874	801.066		107.7	329.000	320.496		34.2		75.000	15.4		749.450
Illinois	5.265.960	3.345.525	910.202	910.202		77.2	4.143.169	4.143.169		241.3	212.589		3.8		3.345.525
Indiana	602.271						532.893	532.893		68.9				69.378	
Iowa	2.212.245	1.590.000	484.478	467.800		87.0	2.110.572	1.687.820		231.3	46,750	142.000	75.1	9.875	1,448.000
Kansas	2.522.401	1.279.419	959.962	959.721		92.9	1.556.240	1.556.240		69.7	6,440		1.7		1.279.419
Kentucky	1.837.926	1.336.409	1.164.252	1.155.636		146.6	683.648	682,263		69.0				27	1.336.409
Louisiana	1.457.148		121.405	121.405		9.2	1,080.400	1.080.400		37.1	94.566		13.0	160.776	
Maine	842.479	427.897	817.320	786.853		76.1	101.373	45.007		4.5				10.618	427.897
Maryland	891.132	1.067.934	371.629	371.629		27.8	454,951	441,025		31.7	45,445	171.816	9.7	33.033	896.118
Massachusetts	488.185		141.634	141.634		5.3	328.108	328.108		9.9				18.444	
Michigan	3.184.057	1.613.142	284.400	284.400		27.9	2.771.330	2.756.430		198.8	26.600		1.1	116.627	1.613.142
Minnesota	2.376.415	1.361.813	1.065.604	1.048.705		149.4	1.239.947	1.239.947		73.1	5.000		1.5	82.764	1.361.813
Mississippi	1.744.669	354.022					1.188.215	1.188.215		128.0	192,182		24.2	364,272	354.022
Missouri	2.923.273	1.852.122	1.438.071	1.429.558		347.0	1.402.407	1.402.291		153.2	4.361	210.517	95.7	87,063	1.641.605
Montana	1.859.937	942.434	1.460.735	1.460.735		190.3	407.643	397.194		35.8				2.008	942.434
Nebraska	1.957.240	991.091	620.311	611.311		103.4	1.299.033	1.298.783		174.8		156.007	101.7	47.145	835,084
Nevada	1.136.479	852.000	956.915	956.915		96.1	135.888	115.888		9.1	24.475	81.638	35.0	39.202	770.362
New Hampshire	477.460	242.365	306.170	265.346		13.7	212.038	212.038		12.0				76	242.365
New Jersey	56.550		56.550	56.550		.5									
New Mexico	1.272.129	735.425	683.923	683.923		130.3	562.192	562.192		163.8				26.014	735.425
New York	3.608.768	4.252.400	1.097.521	994.646		29.8	2.977.100	2.603.625	$ 38.700	70.2		2.034.705	41.3	10.497	2.178.995
North Carolina	2.380.573	1.210.235	996.150	995.751		72.1	988.216	984.331		134.8	279.570		21.1	120,920	1.210.235
North Dakota	1.451.112	734.742	63.050	63.050		20.5	396.081	396.081		101.4	357.037		112.5	634.945	734.742
Ohio	3.871.148	1.966.253	1.791.762	1.743.547		245.9	2,333.080	2.070.178		59.7				57.423	1.966.253
Oklahoma	2.304.199	1.171.295	273.213	273.213		61.2	2,000.210	1.927.820		207.8	55.479		4.1	47,688	1.171.295
Oregon	1.526.724	774.454	1.088.797	983.147		80.8	611.466	530.471		27.6	12.342			765	774,454
Pennsylvania	7.344.822	2.639.003	2,126.647	2.126.235		221.9	5.242.308	5.156.645		431.4	61,942		5.7		2.639.003
Rhode Island	439.716		90.572	90.572		7.8	321.893	321.893		26.4				27.251	
South Carolina	1.364.791	692.739	170.490	170.490		14.2	1.096.017	1.096.017		130.4	98.284		9.2		692.739
South Dakota	1.502.870		541.647	541.647		162.2	468.800	468.800		139.0	411.985		134.2	80.438	
Tennessee	2.123.155	1.075.748	607.601	607.601		53.3	1.239.819	1.239.819		90.4	129.444		6.8	146.291	1.075.748
Texas	6.012.518		3.896.634	3.326.005		556.1	2.483.866	2.312.563		210.6	112.500		.3	261,450	
Utah	1.048.677	533.173	686.131	634.909		127.5	438,182	413.768		39.3		177.612	51.3		355.561
Vermont	438.880	241.354	78.416	78.340		5.2	407.640	360.540		31.5		55.593	3.8		185.761
Virginia	1.699.920	941.347	869.596	827.227		129.2	822.671	793.782		75.8	31.152		.3	47.759	941.347
Washington	1.080.673	776.603	569.212	558.731		36.0	486.933	486.933		27.7	27.739		3.9	7.269	776.603
West Virginia	1.118.559	570.083	92.206	92.206		4.3	832.729	832.729		46.4	50.000		3.2	143.624	570.083
Wisconsin	2.425.385	1.482.551	1.511.598	1.451.554		94.2	815.778	753.989		73.4	94.957		6.1	124.834	1.482.551
Wyoming	1.125.332	571.928	838.100	820.061		127.1	252.544	245.353		21.2	59.918	15.352	13.7		556.576
District of Columbia	959.234	584.305	401.558	401.558		4.2	557.471	557.471		3.6		159.204	.9	205	425.101
Hawaii	187.106						177.718	177.718		4.9				9.389	
TOTALS	92.267.523	46.547.232	34.971.377	33.390.489		4,040.2	53.475.876	51.271.285	38.700	4.264.1	3.307.238	3.386.243	881.7	4.298.511	43.122.289

NOTE: THE APPORTIONMENT AND BALANCE OF 1935 FUNDS ARE INCOMPLETE SINCE THE ASSIGNMENT OF FUNDS TO THE THREE CLASSES HAD NOT BEEN RECEIVED FROM ALL STATES ON AUGUST 31.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF AUGUST 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$8,370,133	$4,259,842	$2,843,981	$1,790,151		115.6	$7,082,489	$5,253,643		408.3	$961,916		70.4	$364,424	$4,259,842
Arizona	5,211,960	2,641,935	3,010,851	2,963,956		193.6	2,599,424	2,022,142		156.7	138,121		.2	87,742	2,641,935
Arkansas	6,748,335	3,428,049	1,553,471	1,395,000		75.4	4,977,366	4,476,662		283.1	500,604		8.1	376,069	3,428,049
California	15,607,354	7,932,206	9,078,746	7,265,810		250.7	10,943,494	7,965,856		295.0	11,205		.7	364,483	7,932,206
Colorado	6,874,530	3,486,006	5,270,445	5,170,380		292.6	1,865,855	1,616,402		73.0	20,319	$239,657	19.2	67,428	3,246,349
Connecticut	2,865,740	1,454,868	645,265	645,265		8.4	2,399,105	2,218,819		47.1	584			1,072	1,454,868
Delaware	1,819,088	923,395	491,558	481,183		8.7	1,058,367	1,058,367		25.8	93,632	543,305	44.2	185,906	380,090
Florida	5,231,834	2,661,343	3,713,700	2,829,863		127.7	2,408,831	2,266,570		81.6	28,546		1.4	106,855	2,661,343
Georgia	10,091,185	5,113,491	2,893,146	2,880,909		182.7	4,242,024	4,227,050		260.2	543,975		32.6	2,439,251	5,113,491
Idaho	4,486,249	2,277,486	2,533,588	2,406,472		242.0	1,941,524	1,899,245		93.5	5,180	187,665	27.4	175,352	2,089,821
Illinois	17,570,770	8,921,401	3,352,316	3,350,910		117.0	12,787,474	12,787,474		323.6	1,223,720		10.6	208,666	8,921,401
Indiana	10,037,843	5,088,963	1,008,464	1,006,379		37.0	7,078,928	7,078,928		221.6	1,252,689		22.3	699,347	5,088,963
Iowa	10,055,660	5,118,361	3,737,730	3,593,845		245.4	6,336,927	5,615,920		391.6	370,350	204,200	115.4	475,545	4,914,161
Kansas	10,089,604	5,117,675	5,803,946	5,795,453		455.1	4,689,888	4,270,952		142.4	23,199	7,212	6.3		5,110,463
Kentucky	7,517,359	3,818,311	3,602,105	3,569,651		317.1	3,143,523	2,978,572		172.3	745,763		12.0	223,372	3,818,311
Louisiana	5,828,591	2,963,932	1,327,306	1,326,073		48.7	4,470,089	3,936,845		101.7	162,118		14.7	403,556	2,963,932
Maine	3,369,917	1,711,586	1,931,863	1,893,780		110.9	1,373,510	1,286,093		30.5				190,044	1,711,586
Maryland	3,564,527	1,810,058	544,724	530,925		33.2	1,788,789	1,774,863		51.7	946,272	295,928	23.9	312,467	1,514,130
Massachusetts	6,597,100	3,350,474	950,346	726,610		27.9	5,763,673	5,527,937		41.6	127,088			215,465	3,350,474
Michigan	12,736,227	6,452,568	2,022,600	2,022,600		82.5	10,323,375	10,244,825		453.7	93,850		1.1	374,952	6,452,568
Minnesota	10,656,569	5,425,551	5,672,142	5,605,815		825.2	4,427,985	4,383,949		264.0	42,130		2.0	624,676	5,425,551
Mississippi	6,978,675	3,540,227	1,514,635	870,329		75.3	5,924,267	4,174,727		361.2	585,453		62.1	1,348,167	3,540,227
Missouri	12,180,306	6,173,740	4,110,341	3,750,219		453.1	7,834,853	7,188,295		304.9	349,378	818,779	125.3	892,414	5,354,961
Montana	7,439,748	3,769,734	5,647,171	5,460,622		484.2	2,428,203	1,911,408		174.7	45,118		3.8	22,600	3,769,734
Nebraska	7,828,961	3,964,364	4,463,369	3,717,162		388.8	4,456,310	4,016,143		284.1	35,183	156,007	103.1	60,472	3,808,357
Nevada	4,545,917	2,302,356	2,836,437	2,836,437		297.9	1,649,794	1,582,845		80.3	67,543	204,673	44.4	59,092	2,097,683
New Hampshire	1,909,839	969,462	1,288,119	1,225,275		31.3	654,619	642,214		21.2				42,350	969,462
New Jersey	6,346,039	3,220,879	506,416	506,416		12.2	5,886,418	5,677,364		58.2	3,846			158,413	3,220,879
New Mexico	5,792,935	2,941,700	3,947,780	3,803,851		405.5	1,650,497	1,650,497		195.8	75,947	111,645	34.5	262,640	2,830,055
New York	22,330,101	11,327,921	5,175,169	4,546,328		99.9	20,061,928	17,061,361	$207,000	312.9	554,106	5,058,705	85.7	168,307	6,062,216
North Carolina	9,522,293	4,840,941	4,121,307	3,661,011		295.6	4,387,789	4,146,765		593.9	985,492		50.1	729,026	4,840,941
North Dakota	5,304,448	2,938,967	2,807,387	2,660,442		842.4	1,706,049	1,448,927		292.5	944,483		176.0	750,596	2,938,967
Ohio	15,484,592	7,865,012	7,172,775	6,875,282		374.5	9,443,958	8,475,578		182.3				133,732	7,865,012
Oklahoma	9,216,798	4,685,180	3,389,279	3,362,057		244.5	5,081,969	5,009,579		364.4	371,113		13.3	474,049	4,685,180
Oregon	6,106,896	3,097,814	3,757,918	3,418,211		220.7	2,738,025	2,541,078		99.0	56,802		.7	90,804	3,097,814
Pennsylvania	18,891,004	9,590,788	5,582,279	5,527,397		303.1	12,990,596	12,533,469		540.5	360,001		6.9	470,137	9,590,788
Rhode Island	1,998,708	1,014,572	761,008	761,008		22.3	1,188,731	1,125,864		38.8				111,836	1,014,572
South Carolina	5,459,165	2,770,954	847,335	847,335		58.3	4,009,371	4,006,237		350.3	290,554		16.6	315,040	2,770,954
South Dakota	6,011,479	3,047,643	2,526,813	2,431,564		438.1	2,700,298	2,371,623		379.5	637,579		185.9	570,712	3,047,643
Tennessee	8,492,619	4,302,991	3,964,301	3,572,240		175.1	4,065,323	3,882,511		172.3	605,160		19.4	432,708	4,302,991
Texas	24,244,024	12,291,253	13,234,859	11,621,687		1,327.1	10,365,448	9,963,071		561.7	1,308,075		11.0	1,351,191	12,291,253
Utah	4,194,708	2,132,691	2,950,983	2,871,460		296.2	1,268,272	1,162,905		83.0		818,417	136.2	160,342	1,314,274
Vermont	1,867,573	948,007	538,943	528,649		25.8	1,421,939	1,328,254		70.3	10,670	87,128	7.1		860,879
Virginia	7,416,757	3,765,387	3,989,719	3,869,703		258.1	3,081,284	2,752,266		110.2	400,812		11.7	393,976	3,765,387
Washington	6,115,867	3,106,412	3,919,526	3,887,057		138.4	2,117,456	2,117,456		63.4	43,657	381,804	15.5	67,696	2,724,608
West Virginia	4,474,234	2,280,335	1,027,685	1,027,685		34.2	3,062,753	3,032,407		108.3	205,516		4.1	208,626	2,280,335
Wisconsin	9,724,881	4,941,837	5,140,688	5,035,325		236.2	4,481,503	4,311,908		212.0	144,113		7.4	233,535	4,941,837
Wyoming	4,501,327	2,287,712	2,647,805	2,441,041		421.0	2,293,954	1,958,240	240,571	250.0	81,126	412,278	73.4	20,920	1,634,863
District of Columbia	1,918,469	973,842	931,610	931,609		7.4	997,499	980,515		5.1		422,485	2.9	6,344	551,357
Hawaii	1,871,062	949,778	196,115	144,003		10.4	1,902,048	1,567,433		29.9	144,921		4.1	14,705	949,778
TOTALS	394,000,000	200,000,000	160,986,065	149,442,935		11,775.0	231,553,794	211,512,054	447,571	10,219.7	15,597,909	9,949,888	1,613.7	17,447,102	189,602,541

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 8 OCTOBER 1934

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Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 15, No. 8 October 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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THE TAXATION OF MOTOR VEHICLES IN 1932

DIGEST OF A REPORT RESULTING FROM A SPECIAL STUDY BY THE U.S. BUREAU OF PUBLIC ROADS

Reported by G. P. ST. CLAIR, Associate Highway Engineer

DURING the summer of 1933 a survey was inaugurated by the Bureau of Public Roads for the purpose of determining the total of all special taxes imposed on the owners of motor vehicles in the United States. The calendar year 1932 was the most recent year which could be studied. A large volume of data was gathered and the work of analysis was not completed until the summer of 1934. A full report of this project is in course of publication, but will not be available in the immediate future. This article is a digest of the essential information produced by the survey.[1]

The effort was made to have the survey as complete as possible, covering all classes of taxing jurisdictions. State taxation of motor vehicles has been adequately reported in past years in the annual compilations of State reports on registration, registration receipts, and gasoline taxes, published by the Bureau. Other agencies, including Government bodies, industrial organizations, and students of taxation, have published figures on the various kinds and amounts of motor-vehicle taxes. The present survey is the broadest in scope yet attempted, as it includes not only State taxes, but also Federal excise taxes, county and municipal taxes, personal-property taxes on motor vehicles imposed by State, county, and municipal jurisdictions, and public bridge tolls.

Only the public charges borne directly by the motor vehicle owner were included in the survey totals. Purposely excluded from the investigation were such indirect charges as automobile dealers' licenses, fines and penalties, real-property taxes on automotive property (factories, garages, truck and bus terminals, etc.), income taxes on motor-vehicle operating enterprises, State chain-store and retail-sales taxes applying to gasoline stations and dealers in automobiles and automotive equipment, and similar imposts which are not evied directly on the ownership and operation of motor vehicles.

REGISTRATION AND TAXATION OF MOTOR VEHICLES IN 1932

STATE FEES AND TAXES

	Vehicles registered and tax-paid	Registration fees paid
Registration:		
Passenger cars, including taxicabs	20,836,362	$214,725,478
Busses	49,452	3,416,697
Trucks and tractor trucks	3,229,315	71,204,768
Trailers and semitrailers	415,276	3,515,345
Motorcycles	89,197	326,889
Total	24,619,602	293,189,177
Special motor-vehicle carrier fees		5,230,792
State gasoline taxes		513,047,239
Operators' and chauffeurs' licenses		18,280,802
Miscellaneous fees and taxes		9,082,968
All State fees and taxes		838,830,978

ALL FEES AND TAXES

Federal manufacturers' excise taxes	$92,378,000
State fees and taxes	838,831,000
County fees and taxes (incomplete)	1,703,000
Municipal fees and taxes (incomplete)	14,158,000
Personal property taxes, all jurisdictions (approximate)	35,880,000
Public bridge and ferry tolls (incomplete)	18,200,000
Grand total	1,001,150,000

The field work was conducted by a force of statisticians, employed through 11 district offices of the Bureau and operating under detailed instructions prepared by the Washington office. The chief statistician in each State was usually a person employed in an administrative office of the State dealing with regulation of motor vehicles, a former employee, or other person thoroughly familiar with the State records.

The work of compiling the data on State taxation of motor vehicles involved a careful and detailed examination of the records of the motor-vehicle department and, in some cases, of other agencies, such as public service commissions regulating for-hire carriers. The work of obtaining data on county and municipal special taxes and personal-property taxes was more difficult, and, necessarily, the results were less complete. While much information was obtained by interviewing State tax officials and by examining the records of central accounting systems, the bulk of the material was derived from answers to questionnaires mailed to county and municipal officials, requesting specific information on local registration and taxation of vehicles.

In the survey as conducted no data were obtained on the payments by motorists of tolls on public bridges and ferries. In order to make the record of motor-vehicle taxation as complete as possible, it was decided to include such payments, and a short study was made in the Washington office of available data on the subject.

RESULTS OF SURVEY SUMMARIZED

The total payments of motor-vehicle taxes, Federal, State, and local, as reported in the 1932 survey, are shown in the tabulation given above. It will be observed that public bridge tolls and county and municipal fees and taxes are marked as incomplete, and that personal-property taxes are marked as approximate. Of these, all totals except that for personal-property taxes are undoubtedly less than the actual payments of such taxes in 1932. The replies to questionnaries on county and municipal taxes were incomplete, as was also the information obtained on the subject of bridge tolls. In the case of personal-property taxes a very thorough study was conducted, and estimates, based on the best information which could be found, were made in cases where the data were not complete. For this reason it is believed that the total payments of personal-property taxes in 1932 were not in excess of the amount tabulated.

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[1] The survey was carried on under the joint supervision of H. S. Fairbank, Chief of he Division of Information, and E. W. James, Chief of the Division of Highway Transport. The work of organizing and directing the field force of statisticians during the summer of 1933 was conducted by H. H. Kelly, of The Division of Highway Transport, and Prof. J. Trueman Thompson, of the Johns Hopkins University. The analysis and compilation of the data were made by H. H. Kelly, A. C. Rose, G. P. St. Clair, L. A. Abbot, and L. S. Tuttle. The material on personal property axation of motor vehicles was prepared by H. R. Briggs.

The number of vehicles (including motorcycles and trailers and semitrailers) reported by the States as registered and tax-paid in 1932 was 24,619,602. The total motor-vehicle tax payments recorded in the survey were slightly more than a billion dollars, or $40.66 per vehicle.

Payments to the State governments, chiefly in the form of registration fees and gasoline taxes, constitute the great bulk of motor-vehicle tax payments. The 1932 total, as reported in the survey, amounted to $838,830,978. In the reports submitted by the statisticians, registrations and payments of registration fees were classified by type of vehicle, class of service, and, in the case of busses, trucks and tractor trucks, and trailers and semitrailers, by size—either by rated capacity or by weight classifications. A similar break-down of payments of special fees by commercial carriers was given in some States, but others failed to classify such payments completely.

In order to reduce the reported figures to a uniform scheme, so that national totals, averages, and percentages might be obtained, a system of approximations was adopted which involved conversions from gross, net, or chassis weight of vehicle to rated capacity and the classification of registered vehicles and corresponding payments in certain chosen capacity groups. It was also decided to estimate the payments of gasoline taxes by the different types, classes, and sizes of vehicles. A systematic method of approximation was adopted and applied to the reported payments of gasoline taxes in all the States. The methods used in this work are discussed later in the report.

STATE FEES AND TAXES SUMMARIZED

Table 1 gives the total number of vehicles of each type and class of service reported in the survey as registered and paying regular fees in 1932, together with corresponding payments of registration and special fees, and estimated gasoline tax payments. Publicly owned and tax-exempt vehicles, where separately reported, were excluded from the tabulation. Averages per vehi-

TABLE 1.—*State taxes imposed on motor vehicles in 1932: national totals, averages, and percentages for vehicles of different types and classes of service*

Type of vehicle and class of service	Number registered	Percentage distribution	Regular registration fees [1]			Estimated payments of gasoline taxes			Special fees and taxes [2]	All fees and taxes		
			Amount collected	Average per vehicle	Percentage distribution	Amount	Average per vehicle	Percentage distribution		Amount	Average per vehicle	Percentage distribution
Passenger cars [3]	20,759,140	84.32	$213,357,330	$10.28	72.89	$375,082,015	$18.07	73.11		$588,439,345	$28.35	72.51
Taxicabs [4]	77,222	.31	1,368,148	17.72	.47	4,682,742	60.64	.91	$117,997	6,168,887	79.89	.76
Passenger cars and taxicabs	20,836,362	84.63	214,725,478	10.31	73.36	379,764,757	18.23	74.02	117,997	594,608,232	28.54	73.27
Busses:												
School [5]	9,813	.04	211,633	21.57	.07	384,393	39.17	.07		596,026	60.74	.08
Contract, including sight-seeing [6]	3,314	.01	157,395	47.49	.06	331,783	100.12	.07	17,372	506,550	152.85	.06
Public-carrier	36,325	.15	3,047,669	83.90	1.04	5,382,256	148.17	1.05	2,287,216	10,717,141	295.03	1.32
All busses	49,452	.20	3,416,697	69.09	1.17	6,098,432	123.32	1.19	2,304,588	11,819,717	239.01	1.46
Trucks and tractor trucks:												
Privately owned and operated [7]	3,144,704	12.78	68,113,536	21.66	23.27	121,046,779	38.49	23.60	1,886	189,162,201	60.15	23.31
Contract-carrier [8]	69,840	.28	2,174,537	31.14	.74	4,361,227	62.44	.85	[9] 1,112,015	[9] 7,647,779	108.35	.94
Common-carrier [10]	14,771	.06	486,474	32.93	.17	1,153,663	78.10	.22	[9] 1,107,187	[9] 2,747,324	183.49	.34
All trucks and tractor trucks	3,229,315	13.12	70,774,547	21.92	24.18	126,561,669	39.19	24.67	2,221,088	199,557,304	61.80	24.59
Trailers and semitrailers:												
Privately owned and operated [11]	406,431	1.65	3,134,711	7.71	1.07					3,134,711	7.71	.39
Contract-carrier [12]	5,008	.02	179,007	35.74	.06				132,315	311,322	62.16	.04
Common-carrier [13]	3,837	.02	131,041	34.15	.05				393,285	524,326	136.65	.06
All trailers and semitrailers	415,276	1.69	3,444,759	8.30	1.18				525,600	3,970,359	9.56	.49
Motorcycles	89,197	.36	326,889	3.66	.11	622,381	6.98	.12	20	949,290	10.64	.12
Undistributed fees [14]									562,306	562,306		.07
All vehicles	24,619,602	100.00	292,688,370	11.89	100.00	513,047,239	21.20	100.00	5,731,599	811,467,208	32.96	100.00
Miscellaneous fees and taxes.												
Operators' and chauffeurs' licenses										18,280,802		
Other fees [15]										9,082,968		
Total										27,363,770	1.11	
Grand total, all fees and taxes										838,830,978	34.07	

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[1] In the case of contract and common carriers of property, registration fees in excess of those based on the rate charged private carriers have been deducted and included with special fees. Total payments of registration fees were $293,189,177, as shown in the box on page 185.

[2] Includes $500,807 in excess registration fees paid by contract and common carriers of property, $2,459,783 in mileage, ton-mile, and passenger-mile taxes, $1,323,413 in receipts taxes, and $1,447,596 in other special fees, including franchise fees, privilege taxes, fees for certificates of convenience and necessity, etc.

[3] Includes taxicabs and other for-hire passenger cars in 20 States for which this item could not be segregated. Hearses and ambulances, where reported separately, have been included with passenger cars.

[4] Totals for 27 States and the District of Columbia. Includes livery cars, U-drive-it cars, and other for-hire passenger cars. In the case of California, taxicabs were included with light delivery trucks.

[5] Totals for 16 States. In other States either there were no tax-paid school busses or they were included with other registration classifications, chiefly public-carrier busses.

[6] Totals for 19 States and the District of Columbia. In other States contract and sight-seeing busses either were not reported or were included with other registration classifications, chiefly public-carrier busses.

[7] Includes contract carriers in 25 States and the District of Columbia and common carriers in 14 States and the District of Columbia, which did not report these classes separately.

[8] Totals for 23 States. (See footnotes 7 and 9.) Includes common carriers in 3 States (Arkansas, Ohio, and West Virginia) which reported these classes together.

[9] These items include payments of special fees to the amount of $80,701 by contract carriers in Montana, Oklahoma, and South Dakota, and $36,971 by common carriers in South Dakota, which were not segregated from privately owned and operated trucks. The numbers of these vehicles and their payments of registration fees and gasoline taxes are included with private trucks. Averages per vehicle, for the items noted, were based on the payments by the 69,840 contract carriers and 14,771 common carriers regularly listed.

[10] Totals for 30 States. (See footnotes 7, 8, and 9.) Massachusetts reported contract carriers, but no common carriers.

[11] Includes contract carriers in 24 States and the District of Columbia, and common carriers in 17 States and the District of Columbia, which did not report these classes separately. Oklahoma had no registration of trailers in 1932; in Kentucky full trailers were not permitted, and semitrailers were included with trucks.

[12] Totals for 20 States. (See footnote 11.) Includes common carriers in 2 States (Arkansas and Ohio) which reported these two classes together.

[13] Totals for 24 States. (See footnotes 11 and 12.) Massachusetts, North Dakota, and Vermont reported no common-carrier trailers or semitrailers.

[14] Special fees which could not be allocated to specific classes of vehicles by reasonable methods of approximation.

[15] Includes fees for reregistrations, transfers, certificates of title, temporary entry permits, nominal fees paid by publicly owned vehicles, etc.

cle and the percentage distributions of registrations and payments are also given. In this tabulation payments of registration fees by contract and common carriers of property in excess of those based on the rates charged private carriers have been deducted from registration fees and placed with special fees and taxes.

Examination of the percentages given in table 1 reveals the following facts:

1. The owners of passenger cars, which constituted 84.3 percent of all vehicles, paid 72.9 percent of the registration fees and 73.1 percent of the gasoline taxes.

2. Taxicabs, reported separately from passenger cars in 27 States and the District of Columbia, comprised 0.3 percent of the vehicles; they contributed 0.5 percent of the registration fees and 0.9 percent of the gasoline taxes.

3. Motor busses, which included 0.2 percent of the vehicles, contributed 1.2 percent of the registration-fee payments and 1.2 percent of the gasoline taxes.

4. Motor trucks and tractor trucks, comprising 13.1 percent of the vehicles, paid 24.2 percent of the registration fees and 24.7 percent of the gasoline taxes.

5. Trailers and semitrailers constituted 1.7 percent of the vehicles and paid 1.2 percent of the registration fees.

Motorcycles, constituting 0.4 percent of the vehicles, contributed 0.1 percent of the registration fees and 0.1 percent of the gasoline taxes.

Special fees to the amount of $5,230,792 were col-ected from operators of vehicles for hire and, in a few States, from certain classes of private operators. These imposts took the form of mileage, ton-mile, r passenger-mile taxes, receipts taxes, special weight r capacity taxes, franchise fees or privilege taxes, ermit fees, and fees for certificates of convenience and ecessity. To this amount must be added $500,807 n excess registration fees paid by for-hire carriers of roperty (fees in excess of those calculated on the rivate-carrier rate). If the special fees are added to he registration fees and gasoline taxes, it is found that usses contributed 1.5 percent and trucks and trailers 5.1 percent of all fees and taxes directly imposed on otor vehicles in 1932.

AVERAGE PAYMENTS SHOW SHARP INCREASE WITH SIZE OF VEHICLE

As the weight or capacity of vehicles increases there , in general, a steady rise in the average fees paid. n table 2 the variation of average payments of regis-ation fees, gasoline taxes, and all fees and taxes is own for public-carrier busses, for all trucks and actor trucks, and for all trailers and semitrailers. hese are national averages for 1932, based on data tained in the survey.

CONCLUSIONS AND COMMENTS

The complexity of the motor-vehicle tax situation in e United States makes it very difficult to draw any onclusions which are both definite and generally plicable. The following statements, however, are pported by the data gathered in this survey.

1. There is an extraordinary lack of uniformity nong the States, both in the methods of motor-vehicle xation and in the magnitudes of the rates charged. e greatest variation was found in the bases on which gistration fees were charged, including gross weight, t weight, chassis weight, capacity, horsepower, value, d various combinations of these factors. The neral adoption of a common basis for registration s is desirable.

TABLE 2. —*Average payments, in 1932, of registration fees, gasoline taxes, and all fees and taxes, by vehicles of different rated capacities*

PUBLIC-CARRIER BUSSES

Rated capacity	Registration fees [1]	Gasoline taxes	All fees and taxes [2]
Passengers:			
7 or less	$25.84	$52.50	$104.77
8 to 20	57.39	123.13	234.50
Over 20	99.20	170.26	329.98

ALL TRUCKS AND TRACTOR TRUCKS

Rated capacity	Registration fees [1]	Gasoline taxes	All fees and taxes [2]
Tons:			
1½ and less	$15.51	$36.16	$51.85
Over 1½ and less than 3	38.21	16.33	85.92
3 and less than 5	67.33	59.89	130.40
5	97.57	68.10	168.49
Over 5	113.89	81.12	199.60

ALL TRAILERS AND SEMITRAILERS

Rated capacity	Registration fees [1]	Gasoline taxes	All fees and taxes [2]
Tons:			
1½ and less	$3.34		$3.42
Over 1½ and less than 3	14.08		15.63
3 and less than 5	36.46		41.71
5	59.21		69.32
Over 5	70.55		92.35

[1] Excess registration fees paid by for-hire carriers of property were included in the calculation of these averages.

[2] Includes special fees.

2. The principle that registration fees should increase with the size of the vehicle, as measured by weight, carrying capacity, horsepower, or cost, is recognized in the laws of all States, the only exception being the District of Columbia, in which a uniform fee of $1 is charged. There is great variety in the application of this principle; in some States the increase of registration fees with size is relatively moderate, while in a few the range is very wide, registration fees in excess of $1,000 being charged against the heaviest vehicles.

3. There is a noticeable tendency for the taxation imposed on motor vehicles to be relatively high in those States in which the intensity of motor-vehicle ownership is low, as indicated by a relatively large number of persons per vehicle. This condition was particularly noted in the Southern States, where the mileage of roads to be improved and maintained is very large in relation to the number of motor vehicles registered.

4. The imposition of unusually high registration fees on heavy vehicles, particularly trucks, in a few States, combined with high gasoline taxes, has apparently discouraged the registration of such vehicles, with the result that the high rates were productive of little revenue in 1932.

5. Comparison of the number of heavy trucks registered in certain States with the existing mileage of high-type roads and particularly of portland cement concrete roads, in the same States, leads to the conclusion that such roads have been built primarily in response to the demands of traffic in general, rather than specifically to support heavy loads.

6. Approximately 9 percent of the revenues derived from State motor-vehicle and gasoline taxes in 1932 were diverted to uses not related to roads and streets. The principal items of diversion included payments to general funds, $39,652,339; unemployment relief, $19,546,456; and schools, $14,522,113.

7. Fees and taxes imposed on motor vehicles by counties in 1932 were negligible in comparison with those imposed by other jurisdictions, the total reported

being less than $2,000,000. Such taxes were found in only 5 States. Fees imposed by municipalities were found in 39 States, and the total amount reported was over $14,000,000.

8. Personal-property taxes were imposed on motor vehicles by either State, county, or local authorities in 31 States and the District of Columbia, the estimated collections being in the neighborhood of $36,000,000. Because of difficulties in assessment and collection the personal-property tax as ordinarily administered is not effectively applied to motor vehicles. Five States and the District of Columbia require that evidence of tax payment be presented before licenses are issued to vehicle owners, thus insuring full collection for all registered vehicles. Seventeen States, containing 46 percent of all registrations, exempted motor vehicles from taxation as personal property.

1933 REGISTRATIONS AND PAYMENTS COMPARED WITH THOSE OF 1932

In table 3 a comparison is made between the payments by motor vehicles in 1932, as given by the survey (plus certain other items) and the data on State motor-vehicle and gasoline taxes for 1933, given in the annual tables published by the Bureau,[2] together with the 1933 payments of Federal excise taxes relating to motor vehicles. No data were obtained on payments in 1933 of county and municipal fees and taxes, personal-property taxes or public bridge tolls, and for this reason no total is given for 1933.

The data for the 2 years are not comparable in all respects because of differences in the manner of reporting; for example, eight States reported busses with trucks in 1933. In order to make the comparison as close as possible, certain modifications have been made in the manner of presenting the 1932 data. In the 1933 table special fees paid in lieu of registration fees in California, Maryland, and South Carolina were tabulated as registration fees. To conform with this procedure, similar payments in 1932 have been deducted from special fees and added to registration fees, the States concerned being those given above and West Virginia. Certain items have been added which were omitted from the 1932 survey totals because they were not regarded as direct taxes imposed on motor-vehicle owners. These include dealers' licenses, certain miscellaneous receipts of the motor-vehicle departments, including fines and penalties in a number of States, and miscellaneous receipts connected with the administration of the gasoline-tax laws. These additions were made in order that the tabulation for 1932 should conform with the published data for 1933.

In comparing vehicle registrations in the 2 years, we find that there was a small decrease in the total number registered, the greatest change being in passenger vehicles. Trailers show a considerable increase. Similar changes occurred in payments of registration fees, although motorcycles show an increase in registrations and a decrease in payments. There was a reduction of 0.9 percent in total registrations and of 8.0 percent in total payments of registration fees.

The relatively large decrease in payments of registration fees was caused by changes in the rates charged.

TABLE 3.—*Comparison of motor-vehicle tax payments in 1932 an 1933*

Item	1932	1933	Increase or decrease in 1933
Vehicles registered:			
Passenger vehicles [1]	20, 885, 814	20, 600, 543	−285, 27
Trucks and tractor trucks	3, 229, 315	[2] 3, 226, 747	−2, 5
Trailers and semitrailers	415, 276	472, 789	+57, 51
Motorcycles	89, 197	91, 987	+2, 7
All vehicles	24, 619, 602	24, 392, 066	−227, 53
Registration fees: [3]			
Passenger vehicles [1]	$218, 907, 499	$195, 841, 695	−$23, 065, 8
Trucks and tractor trucks	71, 444, 038	[2] 70, 298, 260	−1, 145, 77
Trailers and semitrailers	3, 682, 872	4, 298, 007	+615, 1
Motorcycles	326, 889	320, 853	−6, 0
All vehicles	294, 361, 298	270, 758, 815	−23, 602, 4
Special taxes paid by commercial carriers [4]	4, 058, 671	5, 398, 154	+1, 339, 4
Operators' and chauffeurs' licenses	18, 280, 802	18, 075, 282	−205, 5
Certificates of title	4, 340, 239	3, 507, 984	−832, 2
Dealers' licenses and plates [5]	1, 913, 977	1, 596, 647	−317, 3
Miscellaneous fees:			
Included in 1932 survey	4, 742, 729	8, 755, 337	+992, 1
Not included in 1932 survey	3, 020, 457		
State gasoline taxes [6]	514, 138, 900	519, 403, 450	+5, 264, 5
All State fees and taxes	841, 857, 073	827, 495, 669	−17, 361, 4
County fees and taxes (incomplete)	1, 703, 455		
Municipal fees and taxes (incomplete)	14, 157, 822		
Personal-property taxes (estimated)	35, 880, 000		
Federal excise taxes [7]	92, 377, 998	244, 825, 000	+152, 447, 0
Public-bridge and ferry tolls (incomplete)	18, 199, 424		
All fees and taxes	1, 007, 175, 772		+135, 085, 5

[1] Includes private passenger cars, taxicabs and other cars for hire, and busses.

[2] Busses registered with trucks in eight States.

[3] Includes special fees (receipts taxes, ton-mile taxes, and passenger-mile taxes) pa by common-carrier trucks and trailers and public-carrier busses in lieu of registratio fees. Amounts: In 1932, $1,172,121 paid in California, Maryland, South Carolin and West Virginia; in 1933, $1,033,931 paid in California, Maryland, and Sou Carolina.

[4] Special taxes paid in lieu of registration fees deducted. The 1933 figures are inco plete, as a number of States imposing special taxes failed to report them.

[5] Not included in 1932 survey total.

[6] Includes item "other receipts under tax law", $1,091,661 in 1932, and $1,207,738 1933. This item was not included in the 1932 survey total.

[7] Includes Federal excise taxes on gasoline, lubricating oil, tires and inner tub automobiles, motorcycles and trucks, and parts and accessories. Deductions made allow for nonmotor-vehicle use of gasoline and oil.

Drastic reductions in the rates of registration fees we made in Arkansas, Georgia, Kansas, Minnesota, Ne-braska, and South Dakota, and moderate reductions i a number of other States.

There was an increase in the payments of special fe by commercial carriers. This was caused partly b increased revenues from existing taxes and partly b the fact that the number of States regulating and taxin for-hire operations was increased, Maine and Ne Hampshire having enacted laws effective in 193 There were also changes in existing laws and tax relative to such operations in a few States.

The collections of Federal excise taxes on mot vehicles were much greater in 1933 than in 193 The taxes were in effect only for slightly more than months in 1932; and the tax on gasoline was increase from 1 cent to 1½ cents per gallon, effective June 1 1933, reverting to 1 cent on January 1, 1934.

It has been pointed out that the reported figures f county and municipal taxes on motor vehicles in 193 and for public-bridge tolls are incomplete, while tha for personal-property taxes is an approximati believed to be nearly correct. There is no reason believe that there was a decrease in these items f which no data were obtained in 1933. If we assum for the purpose of comparison that they were the sa in both years, we find that the payments of moto vehicle taxes in 1933 exceeded those of 1932 by mo than $135,000,000.

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[2] Table G-1, State Gasoline Taxes, 1933, was published in PUBLIC ROADS, vol. 15, no. 5, July 1934, and tables MV-1 and MV-2, giving State motor-vehicle registrations and fees were published in PUBLIC ROADS, vol. 15, no. 7, September 1934.

STATE FEES AND TAXES

METHOD OF ANALYSIS DESCRIBED

The diverse character of the reports submitted for the 48 States and the District of Columbia imposed a difficult problem of analysis. The object was to reduce all the reports to a uniform basis, in order to obtain comparable figures for each State and to assemble the data in the form of national statistics for different types, classes, and sizes of vehicles. In order to do this it was necessary to make use of certain systematic approximations. The methods used are discussed in detail in the complete report and can only be described briefly here.

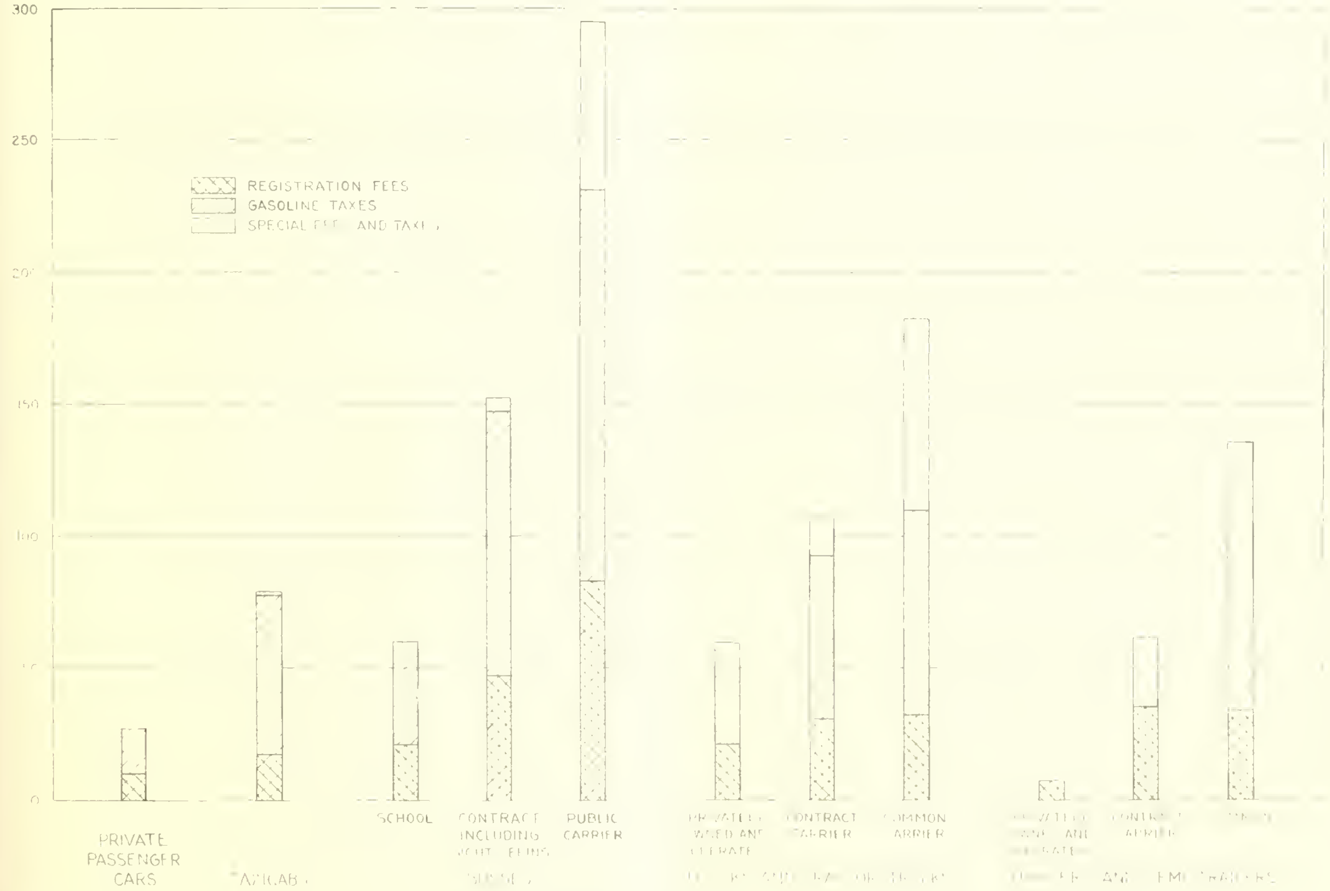
Uniform classification of registrations and fees.—The first of these approximations was occasioned by the necessity of tabulating vehicles of different sizes according to a uniform scheme. It was decided that rated capacity rather than gross or net weight should be the basis of classification. For busses the following grouping by passenger-seating capacity was adopted:

7 or less
8 to 20
Over 20

Trucks, tractor trucks and trailers and semitrailers were arranged in the following groups according to rated capacity in tons:

$1\frac{1}{2}$ or less
Over $1\frac{1}{2}$ and less than 3
3 and less than 5
5
Over 5

In the case of those States which reported vehicles by gross, net, or chassis weight, it was necessary to make conversions into equivalent rated capacity. There is, of course, a considerable range in the net weights of trucks of a given capacity, and also in the gross loads for which, under a given law, they may be taxed. The effort was made, by a study of existing records and by consultation with representatives of the industry, to develop relations between weight and capacity which would represent average conditions, and would, therefore, give a reasonably accurate distribution of vehicles by capacity in those States which reported a weight classification. As an example, the conversion table developed for trucks is given in condensed form in table 4.



Comparison of Average Payments of State Fees and Taxes in 1932 by Vehicles of Different Types and Classes of Service.

A considerable number of the States which reported trucks and trailers according to rated capacity listed them by ton or half-ton groups, or otherwise in such a manner that both the numbers registered and the fees paid could be assembled in the five capacity groups or "brackets" adopted as the basis of classification. Others, however, reported capacity groups which were inconsistent with the chosen scheme. To take care of these cases it was necessary to devise methods of breaking down and rearranging both numbers registered and fees paid. The methods used in grouping the numbers registered were based on certain general relations between the numbers of vehicles of each tonnage, or of each capacity group, determined by analysis of the data for those States which reported trucks and

TABLE 4.—*Approximate relations between manufacturers' rated capacity, chassis weight, net weight, and gross laden weight of trucks* [1]

Manufacturers' rated capacity (tons)	Net weight		Gross weight
	Chassis only	Chassis and body	
	Pounds	*Pounds*	*Pounds*
1	3,000	4,000	6,000
2	4,000	5,600	9,600
3	6,000	8,200	14,200
4	7,600	10,000	18,000
5	9,000	11,680	21,680
7	12,000	15,200	29,200
10	14,000	18,000	38,000

[1] Condensed from full table given in complete report.

trailers by separate tonnages or by capacity groups consistent with those adopted.

In apportioning the fees paid it was necessary to adopt a method consistent with the scheme of rates imposed by the State. In the case of those States where a flat fee was charged each of the tonnage groups separately reported, it was only necessary to make the break-down of fees proportional to the break-down of registrations. In the case of those States which imposed registration fees directly proportional to the weight of the vehicle, it was necessary to take account of this variation in the breakdown of fees.

In the work of arranging vehicles and their fees in uniform classifications two rigid requirements were set: (1) The resulting distribution must be entirely consistent with the original data; (2) the distribution must also, within the limits set by the first requirement, be a reasonable or plausible one, conforming as closely as possible to the national trends. In most States there was surprisingly little room for guesswork if both these requirements were to be fulfilled.

Little difficulty was experienced in arranging busses by passenger capacity; conversions from weight groupings were necessary only in a few States.

Estimate of motor-fuel tax payments.—Any attempt to investigate the payments of fees and taxes by different classes and sizes of motor vehicles would be very incomplete without some sort of estimate of the distribution of gasoline tax payments among the several groups. It was decided, therefore, to make certain assumptions regarding the annual mileage traveled and the rate of fuel consumption for each type of vehicle, class of service, and capacity group. The table "State Gasoline Taxes—1932", published by the Bureau, gives for each State the net tax earning and also the total gallons taxed. The procedure adopted was to compute, for each State, the total gallons consumed by all vehicles registered and tax-paid in each type, class, and capacity group, according to the assumptions made regarding annual mileage and rate of fuel consumption. The total gallonage thus obtained was then corrected by a factor to equal the taxed gallonage reported by that State, and the same factor was applied to all the individual items of gallonage. The corrected items were then multiplied by the tax rate to estimate the amounts paid by each type, class, and capacity group, the summation of these amounts equaling the total gasoline-tax earnings in that State in 1932.

The assumptions made regarding average annual mileage and average rates of gasoline consumption are given in table 5. It is not to be supposed that these assumed values are arbitrary. They were arrived at as a result of a study of available data on the subject, and will be fully discussed in the complete report. The fact that, for each State, the computed gallonages were adjusted so as to add up to the total taxed gallo age tends to make the individual State figures mo nearly correct than the assumed average values.

Allocation of special fees.—In every State but on payments of registration fees were listed in the san detail as were the numbers of vehicles registered. Suc was not the case with the special fees paid by for-hi carriers. Although many of the States listed such pa ments in detail by weight or capacity groups, the were a considerable number which reported only tota for a given group of vehicles, such as common-carri trucks or public-carrier busses, and a few which liste their special fees in even less detail. In order to gi as complete a picture as possible of the payments vehicles in each capacity group, it was decided to all cate payments of special fees in all cases where a reaso able basis could be found for making such a distributio

In general, ton-mile taxes were allocated in proporti to the rated capacities of the vehicles concerned; th procedure is in line with the assumption of the san average annual mileage for all trucks in a given cla of service, regardless of capacity. Similarly, passe ger-mile taxes were allocated in proportion to seati capacity, with the exception that busses of seven pa sengers or less were given a weighting of 0.8, to allo for their assumed annual mileage of 20,000 as co pared with 25,000 for busses of more than 7-passeng capacity.

A number of States impose taxes on the basis of mil traveled, the rate generally increasing with the carryi capacity. In most of these cases the amounts pa were given in detail; where totals only were given, t allocations were made in proportion to the numbers vehicles and the rates per mile.

Receipts taxes were also allocated in proportion carrying capacity. The reason for this procedure not so plain as it is in the case of ton-mile or passenge mile taxes. However, if annual mileage is assumed be independent of capacity, then gross tonnage haul may be taken as proportional to capacity; and, in t absence of data to the contrary, gross receipts may turn be assumed proportional to gross tonnage.

States which imposed privilege taxes or franchi fees on a weight or capacity basis generally gave t receipts from such imposts in detail. Miscellaneo fees yielding small returns, such as fees for certificat of necessity, permit fees, application fees, etc., we

TABLE 5.—*Constants used in the computation of estimat consumption of motor fuel by motor vehicles of different typ classes of service, and rated capacities*

Type of vehicle and class of service	Rated capacity	Assumed rate of consumption of motor fuel	Assumed average annual travel	Annua consum- tion pe vehicl
	Passengers	*Miles per gallon*	*Miles*	*Gallon*
Passenger cars		14.0	7,000	
Taxicabs		14.0	25,000	1,
Motorcycles		35.5	7,000	
Busses:				
School	7 or less	14.0	10,000	
	8 to 20, inclusive	10.0		1,
	Over 20	6.9		1,
Commercial	7 or less	14.0	20,000	1,
	8 to 20, inclusive	8.0	25,000	3,
	Over 20	5.0	25,000	5,
	Tons			
Trucks	1½ and less	10.3	[1] 10,000	
	Over 1½ and less than 3	7.6		1,
	3 and less than 5	6.0		1,
	5	4.9		2,
	Over 5	4.0		2,

[1] For contract, and common-carrier trucks an annual travel of 15,000 miles assumed; for tractor trucks, 20,000 miles.

generally allocated in proportion to the numbers of vehicles.

The foregoing discussion of the methods used in analyzing and compiling the State data brings out the fact that the original reports, as submitted by the Bureau's statistician in each State, have been considerably modified in order that the material in them might be presented in a conventionalized form. All tabulations based on these modifications must be recognized as derived data. The primary data will be published in the complete report, and the opportunity will exist for any investigator to make use of any portion of the original data and obtain his own results, with the aid of such additional material as may be available. A special study of the conditions in any given State would, no doubt, make it possible to determine more accurately the payments made by vehicles of different classes and sizes in that State. It is believed, however, that the material as given presents a reasonable and accurate picture of motor-vehicle taxation in the United States in 1932, and that the figures for the individual States are as near the truth as could be obtained without extension of the Bureau's investigation beyond practicable limits.

The method of analysis described in the preceding paragraphs resulted in a complete table for each State, giving, so far as the original data permitted, the number of registered vehicles of each type, class, and capacity group, and the corresponding payments of registration fees, gasoline taxes, and special fees and taxes, according to the systematic scheme which was adopted. From these State tables national totals, averages, and percentages, such as are given in tables 1 and 2, were computed. More detailed presentation of the national figures is given in the following pages, in which payments by the major types and classes of vehicles are taken up in turn.

It is impossible to give the detailed figures for the individual States in this short digest. However, tables 13, 14, 15, and 16 appearing at the end of the section dealing with State taxes, give for each State the essential data regarding registrations and payments of registration fees, special fees and taxes, and miscellaneous fees. These tables give information for each type of vehicle and class of service, but do not give a break-down by capacity groups.

ITEMS NOT CLASSIFIED OR ALLOCATED

The effort to reduce all data reported by the States to a uniform classification was not entirely successful. In a number of States there were items which could not by any reasonable approximation be made to fit into the general scheme. Since these items continually appear in different steps of the analysis it is thought best to discuss them at this point.

Vehicles not classified by capacity.—In cases where the bulk of vehicles in a given group were classified by weight or capacity, but a small remainder were given without classification, the practice was adopted of making an approximate distribution of the unclassified vehicles, generally in proportion to those classified.

There were, however, some cases where an entire group of vehicles was unclassified. Under these circumstances there was no reasonable basis for assuming a distribution by capacity. In order to account for the gasoline consumed and the gasoline taxes paid by vehicles not classified, estimates were made on the assumption that unclassified busses belonged to the capacity group, 8 to 20 passengers, and that unclassified tractor trucks belonged to the capacity group, over 1½ and less than 3 tons. In all tabulations by capacity, however, unclassified vehicles are listed separately.

The total number of these unclassified vehicles was 35,608 or 0.14 percent of all vehicles registered and tax-paid. The total payments involved, including estimated payments of gasoline taxes, were $1,440,896, or 0.17 percent of all State fees and taxes.

For-hire trucks not segregated from private carriers.—In a few States the numbers and registration fees of contract or common carriers, or both, were tabulated with those of private carriers, although the numbers of such for-hire carriers were also listed separately, with their payments of special fees. In most cases it was possible, by computing average fees, to approximate the payments of registration fees by the for-hire carriers, and tabulate them separately in the proper capacity groups. Exceptions occurred, however, with respect to 297 contract-carrier trucks in Montana, 647 contract-carrier trucks in Oklahoma, and 172 contract-carrier and 2,098 common-carrier trucks in South Dakota. These trucks were not classified by weight or capacity, although the totals of all trucks in these States (in which these for-hire carriers were included) were so classified. It would have been possible to assume a capacity distribution for these vehicles, but it was believed that such a degree of approximation was unwarranted. Without such a distribution it was impossible to segregate these trucks from the classified lists of trucks in which they were included. The special fees paid by these "unsegregated" vehicles included $80,701 paid by contract carriers in Montana, Oklahoma, and South Dakota, and $36,971 paid by common carriers in South Dakota. The method of handling these items in the compilation of national totals and averages is shown in footnote 9 of table 1.

A similar situation, even more difficult to deal with, occurred in the case of Tennessee. In this State it was reported that there were 397 for-hire carriers of property, including trucks, tractor trucks, trailers, and semitrailers, under the jurisdiction of the Railroad and Public Utilities Commission. Fees paid by these vehicles were reported as follows:

Registration fees	$21, 199
Mileage tax	17, 383
Inspection fees	1, 695

These vehicles and their payments of registration fees and mileage taxes were included in the tabulations of trucks, tractor trucks, and trailers and semitrailers without regard to class of service. The inspection fee was reported as applying to these vehicles only. However, since they could not be classified either by type or by capacity, there was no way of segregating them from private carriers. Their payments of special fees are included with the "undistributed fees", which are discussed in the next section.

Undistributed fees.—In addition to the items described in the preceding paragraphs, fees were reported in a number of States which could not be allocated to any given numbers or groups of vehicles in the conventional scheme of classification. The total amount of money involved was $851,993, of which $11,536 consisted of registration fees and $840,457 of special fees and taxes paid by commercial carriers.

The nature of these unallocated items will be made clear by a few illustrations. In Kansas a ton-mile tax was imposed on for-hire carriers of persons and property and certain classes of private carriers. The receipts from this tax in 1932, $186,153, were reported in a lump sum, and no reasonable basis could be found for allocating this sum among the several classes of freight and passenger carriers. Similarly, in Pennsylvania, a receipts tax on for-hire carriers of persons and property, yielding $33,946, was not allocated. In Wisconsin contract carriers of property were not reported separately from those privately owned and operated, although the former (and certain private carriers as well) were required to pay a ton-mile tax and certain permit fees. These payments, amounting to $246,888, could not be assigned to any specific group of vehicles, and were therefore carried as "undistributed". In this same State, and in Ohio and Iowa, fees paid by out-of-State vehicles could not be allocated among vehicles of the State, although they were assigned to the proper classes in the national totals.

Of the $840,457 in undistributed special fees, a total of $278,151 was, in the national totals, allocated by class of service (but not by capacity). The remainder, $562,306, is listed in table 1 as "undistributed fees." The footnotes to table 15 give further information on these troublesome items.

REGISTRATIONS AND PAYMENTS BY PASSENGER CARS DISCUSSED

The total number of passenger automobiles reported in the 1932 survey was 20,836,362. This total includes 77,222 taxicabs and other for-hire cars reported separately from private passenger cars in 27 States and the District of Columbia. Twenty States failed to segregate taxicabs from private cars, and one State, California, included them with light trucks. The figure given for passenger cars in table 1—20,759,140—includes for-hire cars in these 20 States. It also includes ambulances and hearses in a number of States which reported such vehicles separately. Similarly, snowmobiles, reported by a few States, were included with passenger cars. Publicly owned vehicles are not included, except in the case of a few States which failed, wholly or in part, to segregate such vehicles from those paying regular registration fees.

Total and average payments by passenger cars were as follows:

Registration fees:	
Total payments	$213, 357, 330
Average per vehicle	10. 28
Gasoline taxes:	
Total payments	375, 082, 015
Average per vehicle	18. 07
All fees and taxes:	
Total payments	588, 439, 345
Average per vehicle	28. 35

The registration fees imposed on passenger cars varied with the size of vehicle in all but three States, California and Washington, in which a fee of $3 was charged, and Arizona, in which the rate was $3.50. In the District of Columbia a $1 fee is charged against all gasoline-driven automobiles. Weight was the most common measure of size, 30 States using it as the basis of fee, either alone or in combination with other factors. Horsepower was used as a basis in 18 States and value or list price in three.

Average payments of registration fees ranged from $1 in the District of Columbia to $21.45 in Vermont. Among the low States were Washington, with $2.94; California, with $3.02; Arizona, with $3.50; Massachusetts, with $3.58; and Colorado, with $4.94. States which exacted relatively high fees from their passenger cars were Oregon, in which the average payment was $21; Arkansas, with $19; Connecticut, with $17; and Florida, with $16. Clustered about the average were New Jersey, Kansas, Pennsylvania, Wyoming, and North Dakota, all charging averages of $10 and $11.

The method of estimating gasoline-tax payments has been described (see p. 190). Differences among the States in the estimated average payments are dependen on differences in the gasoline-tax rates and the average per-vehicle consumption of gasoline. The range in gasoline-tax payments, as computed, extended from $9.77 in the District of Columbia to $44 in Florida North Dakota was the lowest in gasoline-tax payments other than the District of Columbia, with an average for passenger cars of $10.32. Among the high States were Tennessee, with $36; Georgia, with $35; Arkansas with $32; and South Carolina, with $32. In Tennessee and Florida the rate is 7 cents per gallon; in the others mentioned as high States the rate is 6 cents.

In total payments the District of Columbia, with a $1 registration fee and a gasoline-tax rate of 2 cents per gallon, is naturally the minimum with an average payment of $10.77. California comes next, with $19 The largest payments were found in Florida, $60 Arkansas, $50; Georgia, $48; and Tennessee, $47 New York, Connecticut, Arizona, and Texas were within $1 of the national average of $28.35.

TAXICAB PAYMENTS GENERALLY HIGHER THAN THOSE FOR PRIVATE PASSENGER VEHICLES

Nearly all of the 27 States which reported taxicabs charged heavier registration fees against them than against private passenger cars. In Colorado, Georgia Maryland, Nevada, Oregon, Vermont, and the Distric of Columbia, the rates were the same as for private cars In all except Maryland and the District of Columbia however, the average payments by taxicabs exceeded those of private cars.

The total and average fees paid by the 77,222 taxicabs reported separately were as follows:

Registration fees:	
Total payments	$1, 368, 148. 00
Average per vehicle	17. 72
Gasoline taxes:	
Total payments	4, 682, 742. 00
Average per vehicle	60. 64
Special fees	117, 997. 00
All fees and taxes:	
Total payments	6, 168, 887. 00
Average per vehicle	79. 89

The average for special fees is not given, as they were imposed in only a few States.

After the District of Columbia, Colorado charged the minimum registration fees, with an average of $5.1 for taxicabs, Maryland following with $7.36. The maximum occurred in West Virginia, in which the average payment was $59. In North Carolina it was $55 and in Connecticut, $46.

Average payments of all fees and taxes by taxicabs ranged from $50 in the District of Columbia to $200 in Florida. Among the low States were North Dakota with $59, and New Jersey and New York, with $70

Gasoline-tax payments by taxicabs were estimated on the basis of an average annual mileage of 25,000 miles. (See table 5.) There is no point in discussing these payments, as they are proportional to the payments reported for passenger cars in the State represented.

Special fees and taxes paid by taxicabs or other car for hire were reported in six States and the District o Columbia, the total payments amounting to $117,997

These special taxes included a receipts tax in Arizona, an occupation tax on U-Drive-It systems in Georgia, special-license taxes in Nevada, Oregon, and the District of Columbia, fees for certificates of convenience and necessity in North Dakota, and a privilege tax in Tennessee. Details of the payments are given in the first two columns of figures in table 15. Taxicabs also participated in the payment of the receipts tax in Pennsylvania, previously mentioned, but their payments could not be segregated from those of other vehicles.

BUSSES REPORTED IN THREE CLASSES

In the instructions to the statisticians who collected the data on State motor-vehicle taxes, it was requested that busses be reported in three classes (1) school and private busses, (2) sight-seeing and other contract-carrier busses, and (3) public-carrier busses. All of the 16 States which reported tax-paid busses in the first class described them as school busses. It is to be inferred that privately owned and operated busses such as those owned by factories, real-estate developers, and various private institutions, were reported with other registration classifications.

Nine States reported busses in all three classes. Seven States reported tax-paid school busses, but did not segregate sight-seeing or contract-carrier busses from other classes of vehicles. Ten States and the District of Columbia reported busses in the contract-sight-seeing class, but did not report tax-paid school busses. The remaining States failed to report any tax-paid school busses or to segregate sight-seeing and contract-carrier busses from other registration classifications. Commercially operated busses, either public carriers or a combination of public and contract carriers, were reported in all the States.

The numbers of busses reported in the three classifications in the 1932 survey were as follows:

School busses	9, 813
Contract-carrier busses, including sight-seeing	3, 314
Public-carrier busses	36, 325
Total	49, 452

It should be remembered that only tax-paid school busses are included in the survey total. No attempt was made to obtain an accurate count of publicly owned or tax-exempt school busses. Approximately 12,700 publicly owned busses were reported by the States. It was apparent, however, that the reporting of publicly owned and tax-exempt vehicles was very incomplete. Other sources[3] indicate that the number of school busses in operation in 1932 was between 60,000 and 70,000.

The number of busses reported as engaged in commercial operations (sight-seeing, contract, and public-carrier) was 39,639. In a number of States, including Georgia, Mississippi, Ohio, South Carolina, Texas, and possibly others, busses operating in cities were not reported separately or as public carriers, but were included in other classifications, particularly passenger cars and trucks. The figure given by Bus Transportation[3] for commercial or "revenue" busses was 42,348. City busses were given separately in this tabulation; and in the five States mentioned above 1,518 city busses were reported. The agreement between the two surveys appears sufficiently close when it is remembered that the Bus Transportation figures were obtained very largely from operating companies, while those obtained in this survey were taken from State records, which frequently do not separate all vehicles operating as busses from other classifications.

BUS REGISTRATION RATES VARIED WIDELY

In the 16 States which reported tax-paid school busses, they were commonly registered according to weight or capacity, although in several States flat fees were charged, ranging from $2 per vehicle in Massachusetts to $75 per vehicle in West Virginia. In general, sight-seeing and contract-carrier busses were registered at considerably higher rates than school busses and not infrequently the fees corresponded to those paid by public-carrier busses.

In all States (the District of Columbia excepted) the registration fees imposed on public-carrier busses were graduated to increase with the size of the vehicle. Weight, either alone or in combination with other factors, was a common basis of registration, 9 States reporting a gross-weight and 15 a net-weight basis. Seating capacity appeared as a basis of registration fee in 27 States; in 10 of these capacity alone was the basis, while in the remainder it was used in combination with other factors.

There was great variety in the rates of fees imposed, even in those States in which registration fees were based on the same factors. In the seven States which used gross weight as a single basis of taxation, the minimum rate reported was that in Nevada, 30 cents per 100 pounds. In Vermont the rate was $1 per 100 pounds, and in Delaware, 40 cents. In New Hampshire, Illinois, Wisconsin, and Texas the rate itself varied with the weight; the highest rate reported was $4 per 100 pounds, charged in Texas against busses having a gross weight of more than 28,000 pounds.

In the six States basing registration fees on net weight alone, the fees varied from 50 cents to $2.25 per 100 pounds, the latter rate being charged in Ohio for that portion of the weight of the vehicle in excess of 10,000 pounds.

Where capacity was the basis of registration fees, the rates charged varied so widely for busses of different sizes that a direct comparison of rates is not feasible. An example may be given, however. In the 10 States registering busses on the basis of capacity alone, 30-passenger busses were required to pay registration fees varying from $18 in Missouri to $180 in Indiana.

SPECIAL FEES IMPORTANT FACTOR IN TAXATION OF BUSSES

In addition to registration fees the majority of States imposed some form of special tax on busses operated for hire, particularly public carriers. In four States the special tax was imposed in lieu of registration fees, a receipts tax in California and passenger-mile taxes in Maryland, West Virginia, and South Carolina.

Mileage, ton-mile, and passenger-mile taxes. Taxes based on the operations of public-carrier busses were imposed in 19 States and the District of Columbia. Mileage taxes (i.e., those in which the charge is directly proportional to the miles traveled) were found in Alabama, Florida, Georgia, Kentucky, Mississippi, New Jersey, New Mexico, Oklahoma, Tennessee, and the District of Columbia. In all except New Jersey and the District of Columbia, the rate per mile increased with the seating capacity. In Florida, for example, the rate was ½ cent per mile for busses of 10 passengers or less, ¾ cent per mile for 11 to 20 passengers, and 1 cent for more than 20 passengers. In New Jersey the tax was levied against interstate busses only.

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[3] Bus transportation, February 1933, McGraw-Hill Publishing Co., Inc., New York City; and Circular No. 132, Office of Education, United States Department of the Interior, Consolidation of Schools and Transportation of Pupils, 1929–32, by David T. Blose.

Taxes assessed at a constant rate against operations in terms of ton-miles or passenger-miles were found in 10 States. In Wyoming, Colorado, and Utah, the rates were based on the actual number of passengers carried times the actual miles each as carried. In Wyoming the rate was 1/20 cent per passenger-mile; in Colorado, 1/10 cent; and in Utah, 1/4 cent on hard-surfaced roads and 1/10 cent on other roads.

In all other States using this form of tax the rate was based either on passenger capacity or on the gross weight of vehicle, plus capacity load, allowing 150 pounds per passenger. The former basis was used in Maryland, Oregon, South Carolina, and West Virginia; the latter in Iowa, Kansas, and Wisconsin. The rates per passenger seat-mile varied from as low as 1/50 cent in South Carolina to 1/15 cent in West Virginia. The rate per ton-mile in Iowa was 1/4 cent; in Kansas, 1/20 cent; and in Wisconsin 1/10 cent.

Mileage taxes were imposed on contract and sight-seeing busses in Florida and Oklahoma, and in Utah such vehicles participated in the payment of the passenger-mile tax.

Receipts taxes.—Ten States—Arizona, Arkansas, California, Connecticut, Idaho, North Carolina, Pennsylvania, South Dakota, Virginia, and Washington—imposed fees in the form of a percentage tax on the revenues derived from the operations of public-carrier busses within the State. The receipts tax was imposed in addition to the registration fee in all these States except California, where the tax was in lieu of registration fees, and North Carolina, where the registration fee was credited on the amount collectible in receipts taxes. The rates varied from eight-tenths of 1 percent in Pennsylvania to 6 percent in North Carolina.

Other special fees.—Special fees other than receipts taxes and those based on mileage were reported by 17 States in the case of public-carrier busses and by 3 States and the District of Columbia in the case of sight-seeing or contract-carrier busses. Although imposed under various names, such fees may be roughly divided into three classes.

Most numerous were fees required for the issuance of certificates of convenience and necessity, or for equivalent permits to operate, which were imposed in Alabama, Georgia, Kentucky, Minnesota, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Wisconsin, and Wyoming. Certificate fees are usually nominal flat fees which are paid when the certificate is applied for, and are not generally assessed annually. As ordinarily issued, the certificate empowers a company to operate over a specified route or routes, and the fee is independent of the number of vehicles to be operated.

A second class of fees were those charged for permits to operate, at a flat rate per vehicle. Such fees were charged against public-carrier busses in Georgia, Montana, and Wisconsin, the rates being $25, $10, and $40, respectively. Sight-seeing busses in the District of Columbia paid a $100 fee.

A number of States imposed, under various names, special-license taxes which varied with the weight or capacity of the vehicle, in much the same manner as registration fees. Such fees were imposed on public-carrier busses in Michigan, Nevada, Ohio, Tennessee, and Texas; and on contract and sight-seeing busses in Oklahoma and Oregon.

City busses.—In a number of States a distinction was made between busses operated exclusively or customarily in urban service only, and those operating on the rural roads. Thus, in New York, city busses, termed "special-franchise" busses, paid registration fees at a flat rate of $10 each, while interurban busses paid fees ranging from $30.50 for those seating 8 to 10 passengers, to $67.50 plus $2 for each seat over 30 for those seating 31 passengers or more. The receipts tax in North Carolina was imposed only on interurban busses; in lieu of this tax city busses were charged heavier registration fees than the interurban busses. In Georgia city busses were exempted from the payment of certificate fees, permit fees, and mileage taxes imposed on interurban public carriers, but were required to pay an occupation tax. Similar exemptions or separate provisions for city busses were found in South Carolina, Ohio, Wisconsin, Kansas, Kentucky, Tennessee, Mississippi, Texas, New Mexico, and Oregon.

BUS PAYMENTS DISCUSSED

A total of $211,633 was paid in registration fees by the 9,813 tax-paid school busses. Estimated payments of gasoline taxes were $384,393. Average payments of registration fees ranged from a rate of $2 in Massachusetts to an average of $128, paid by school busses carrying over 20 passengers in Oregon. In some States publicly owned school busses were charged nominal fees, varying from 25 cents to $1. In most States the fees were graduated according to seating capacity or weight. Average payments by the three capacity groups were as follows:

7 passengers or less:	
Registration fees	$10. 63
Gasoline taxes	22. 14
All fees and taxes	32. 77
8 to 20 passengers:	
Registration fees	24. 85
Gasoline taxes	35. 96
All fees and taxes	60. 81
Over 20 passengers:	
Registration fees	62. 77
Gasoline taxes	48. 77
All fees and taxes	111. 54

In table 6 is given a summary, by capacity groups, of the registrations, total payments, and average payments of contract and public-carrier busses. Associated with each class of fee is the number of vehicles in each capacity group concerned in the payment of such fees. Special fees are divided into three classes, (1) mileage, ton-mile, and passenger-mile taxes, (2) receipts taxes, and (3) other special fees. This latter class includes franchise, privilege or special license taxes, permit fees, and fees for certificates of convenience and necessity.

In table 6 all the averages are based on the number of vehicles involved in the payments tabulated. In certain cases, covered by footnotes, the total number of vehicles involved is not known, and the average is omitted. It may be observed that certain of the averages computed in this manner differ from those given in table 1, which are based on all the vehicles registered in a given class or group. For example, the average payment of registration fees by public-carrier busses, based on the total of 36,325 public-carrier busses registered, was $84; based on the 33,246 busses which actually paid registration fees, the average is $92. Average gasoline-tax payments and the averages of all fees and taxes are, of course, the same in all tables.

The payments by busses in individual States are given in tables 14 and 15. Average payments of

TABLE 6.—*State taxes imposed on contract- and public-carrier busses in 1932; national totals and averages*

Rated capacity	Number registered	Estimated payments of motor-fuel taxes		Registration fees			Registration fees and motor-fuel taxes			Mileage, ton-mile or passenger-mile taxes		
		Amount	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle
Passengers												
Contract, including sight-seeing:												
7 or less	1,862	$99,113	$53.23	1,862	$22,077	$11.86	1,862	$121,190	$65.09	61	$1,990	$32.62
8 to 20, inclusive	477	65,626	137.58	477	18,493	38.77	477	84,119	176.35	33	2,530	76.67
Over 20	490	120,136	245.18	490	43,197	88.16	490	163,333	333.34	26	4,538	174.54
Total classified	2,829	284,875	100.70	2,829	83,767	29.61	2,829	368,642	130.31	120	9,058	75.48
Not classified by capacity [1]	485	46,908	96.72	485	73,628	151.81	485	120,536	248.53			
Total	3,314	331,783	100.12	3,314	157,395	47.49	3,314	489,178	147.61	120	9,058	75.48
Public carrier:												
7 or less	3,630	190,593	52.50	3,348	93,787	28.01	3,630	284,380	78.34	1,936	55,472	28.65
8 to 20, inclusive	7,176	883,604	123.13	6,400	111,815	64.35	7,176	1,295,419	180.52	1,533	224,335	146.34
Over 20	24,873	4,234,921	170.26	22,958	2,467,390	107.47	24,873	6,702,311	269.46	2,873	790,380	275.11
Total classified	35,679	5,309,118	148.80	32,706	2,972,992	90.90	35,679	8,282,110	232.13	6,342	1,070,187	168.75
Not classified by capacity [1]	646	73,138	113.22	540	65,659	121.59	646	138,797	214.86	106	28,896	272.60
Undistributed fees [2]					9,018			9,018			154,648	
Total	36,325	5,382,256	148.17	33,246	3,047,669	91.67	36,325	8,429,925	232.07	[3] 6,448	1,253,731	

Rated capacity	Receipts taxes			Franchise fees, certificate fees, and other miscellaneous special fees			All special fees			All fees and taxes		
	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle
Passengers												
Contract, including sight-seeing:												
7 or less				192	$2,525	$13.15	225	$4,515	$20.07	1,862	$125,705	$67.51
8 to 20, inclusive				24	780	32.50	52	3,310	63.65	477	87,429	183.29
Over 20				51	5,009	98.22	72	9,547	132.60	490	172,880	352.82
Total classified				267	8,314	31.14	349	17,372	49.78	2,829	386,014	136.45
Not classified by capacity [1]										485	120,536	248.53
Total				267	8,314	31.14	349	17,372	49.78	3,314	506,550	152.85
Public carrier:												
7 or less	529	$26,005	$49.16	665	14,479	21.77	2,876	95,956	33.36	3,630	380,336	104.77
8 to 20, inclusive	1,150	116,031	100.90	1,584	47,018	29.68	3,646	387,384	106.25	7,176	1,682,803	234.50
Over 20	2,727	596,853	218.87	2,124	118,184	55.64	7,156	1,505,417	210.37	24,873	8,207,728	329.98
Total classified	4,406	738,889	167.70	4,373	179,681	41.09	13,678	1,988,757	145.40	35,679	10,270,867	287.80
Not classified by capacity [1]				540	64,736	119.88	646	93,632	144.94	646	232,429	359.87
Undistributed fees [2]					50,179			204,827			213,845	
Total	4,406	738,889	167.70	[4] 4,913	294,596		[5] 14,324	2,287,216		36,325	10,717,141	295.03

[1] See p. 191.

[2] See pp. 191 and 192.

[3] Does not include unknown number of busses in Tennessee paying mileage taxes of $72,288, and unknown number of interstate busses paying mileage taxes of $79,802 in New Jersey. These amounts are included in "Undistributed fees" on preceding line.

[4] Does not include unknown number of busses in Tennessee paying privilege taxes of $8,510 and inspection fees of $10,263. These amounts are included in "Undistributed fees" on preceding line.

[5] See footnotes 4 and 5.

registration fees by public-carrier busses varied from $1 in the District of Columbia and $11 in Montana to $518 in Minnesota. Other States in which the payments were high were Wisconsin, with $492; Florida, with $255; and Idaho, with $252.

Payments of special fees by public-carrier busses, not including items in Pennsylvania, Kansas, and New Mexico, which were not segregated from payments by other carriers, were $2,287,216. Mileage, ton-mile, and passenger-mile taxes were the most lucrative, the revenues from this form of taxation totaling $1,253,731. It is apparent that special taxes formed a significant part of the total payments by busses. In a few States the payments were very high. Payments of ton-mile taxes by public-carrier busses in Iowa averaged $656 per vehicle; the mileage tax in Florida yielded $242 per bus; the receipts tax in California (imposed in lieu of registration fees) produced an average payment of $260.

In the payments of all fees and taxes, including registration fees, gasoline taxes, and special fees, the highest average was found in Iowa. Public-carrier busses in that State paid an average of $932 per vehicle. This is an average for Iowa-licensed vehicles, payments by out-of-State vehicles having been eliminated from the computation. Other States in which the payments were high were Wisconsin, with $828; Florida, with $772; Minnesota, with $638; and Tennessee, with $540. Payments were relatively low in Montana, in which the average was $112. Other States with low averages were Colorado, with $114; North Dakota, with $155; and the District of Columbia, with $175.

The averages given above are for all busses in the States concerned, and their magnitudes are naturally affected by the relative numbers of light and heavy busses. That the scale of payments increased rapidly with the size of bus is evident from an inspection of table 6. A few examples will serve to point the fact more clearly. In Minnesota busses having capacity of more than 20 passengers paid in registration fees an average of $564 per vehicle; in Wisconsin the average was $543. Average payments of all fees and taxes by busses in this class in Minnesota were $692; in Florida, $861; in Wisconsin, $901; in Iowa, $1,212.

COMPARISON OF FEES REQUIRED FOR TYPICAL PUBLIC-CARRIER BUS OPERATION

In order to show the extremes of variation in tax payments required of public-carrier busses under comparable operating conditions, an example has been computed to show the State fees and taxes which would have been paid in 1932 by a 30-passenger bus operating 25,000 miles. The States selected for comparison were Rhode Island, New York, Florida, Michigan, and Oregon.

The net weight of the 30-passenger bus is taken as 10,700 pounds, and the gross weight, at 150 pounds per passenger, is 15,200 pounds. At an assumed rate of 5 miles per gallon of gasoline, the bus would consume 5,000 gallons per year. The rates of fees required in the 5 States are given in the following paragraphs.

Rhode Island: A registration fee of $46 plus $2 per passenger seat and a gasoline tax of 2 cents per gallon.

New York: A registration fee of $67.50 and a gasoline tax of 2 cents from January 1 to February 29 and 3 cents beginning March 1, the average payment for the year being approximately 2.86 cents per gallon.

Florida: A registration fee of $2 per 100 pounds net weight plus $20 per passenger seat, a gasoline tax of 7 cents per gallon, and a car-mile tax of 1 cent per mile.

Michigan: A registration fee of $1.25 per 100 pounds net weight, a gasoline tax of 3 cents per gallon, and a public utility permit fee of $1 per 100 pounds net weight.

Oregon: A registration fee of $1.10 per 100 pounds net weight, a gasoline tax of 4 cents per gallon, and a passenger-mile tax of 0.5 mill per capacity seat-mile.

In the case of Florida, in which the required payments were the highest, the items making up the total are as follows:

Registration fee	$814
Gasoline tax	350
Car-mile tax	250
Total	1,414

The total payments which would be required in the five States chosen for comparison, arranged in descending order of magnitude, are given below:

Florida	$1,414.00
Oregon	692.70
Michigan	390.75
New York	210.50
Rhode Island	206.00

PAYMENTS BY TRUCKS AND OTHER FREIGHT VEHICLES ANALYZED

In the instructions to statisticians it was requested that freight vehicles be reported in three groups, trucks, tractor trucks, and trailers and semitrailers. Only 23 States, however, reported tractor trucks separately from trucks, and in several of these there was evidence that the figures were incomplete. In general, tractor trucks are registered and taxed on much the same basis as trucks, and no separate data regarding them are given in this digest. Trailers and semitrailers were reported by all States except two—Kentucky and Oklahoma. In Kentucky full trailers are prohibited and tractor-semitrailer units are registered as trucks. In Oklahoma there was no registration of trailers in 1932.

In every State (the District of Columbia excepted) the registration fees of trucks were graduated so as to increase with the size of vehicle. In contrast to passenger cars and busses, for which weight was the most common basis of registration fee, trucks were registered according to carrying capacity in the majority of the States in 1932. Capacity, alone or in combination with a flat fee, weight, or horsepower, appears in 26 States as the basis of registration fee for privately owned and operated trucks. Twenty-two States registered trucks according to weight, the basis being gross weight in 11 States, net weight in 8 States, and chassis weight in Pennsylvania, South Dakota, and Idaho. A flat fee in combination with weight or capacity appeared as the basis in 6 States. Maryland was the only State which imposed fees according to horsepower alone; but horsepower in combination with capacity was reported in Tennessee and Louisiana. Minnesota alone used value as a basis.

Registration fees for private trucks were modified according to age or the number of previous registrations in 5 States, although in Mississippi reduction of fee for age was applied only to trucks of less than 2½ tons capacity, and was effective only after July 1, 1932.

Space does not permit a tabulation or full discussion of the registration fees imposed on trucks. For present purposes a comparison of the rates in a few States in different parts of the country will serve to illustrate the variety and range in the registration fees charged against trucks in 1932. In all cases the rates given are for 4-wheel, pneumatic-tired trucks.

Capacity States.—In Connecticut the rates varied from $15 for a ½-ton truck to $217.50 for a 6½-ton truck, with $75 additional for each ton or fraction thereof over 6½ tons. In Georgia, the fees ranged from $15 for 1 ton or less to $1,125 for 7 tons or over. In Missouri trucks of less than 2 tons capacity paid $10.50; those of 7 and less than 8 tons capacity paid $36, and $15 was paid for each ton in excess of 8. In Oklahoma $15 was paid by trucks having a capacity of three-fourths of a ton or less, and $300 by all of over 4 tons. In Utah the rates varied from $5 for a ½-ton truck to $100 for a 5-ton truck, with $50 additional for each ton over 5.

Gross-weight States.—In Massachusetts the fee charged was 15 cents per 100 pounds weight of the vehicle and its maximum carrying capacity, with a minimum fee of $6. In North Carolina, the rates, although based on gross weight, varied with the rated capacity. For trucks of 2 tons capacity or less the rate was 55 cents per 100 pounds, gross weight; for 2 tons to 3 tons the rate was 70 cents per 100 pounds; for more than 3 tons, the rate was $1 per 100 pounds. The minimum fee was $15. In Illinois the rates varied from $10 for trucks having a gross weight of 3,000 pounds or less to $150 for gross weights between 20,000 and 24,000 pounds. In Texas a rate of 40 cents per 100 pounds was charged for gross weights of 6,000 pounds or less. The rate increased with the weight until it reached $4 per 100 pounds for weights over 26,000 pounds.

Net-weight States.—In New York a flat rate of $12 was charged for trucks weighing less than 1,800 pounds. For other trucks a rate of 80 cents per 100 pounds net weight was charged. In Florida trucks weighing 4,000 pounds or less paid 75 cents per 100 pounds; trucks weighing over 4,000 pounds paid $2 per 100 pounds. In Michigan the rate varied from 65 cents per 100 pounds for trucks weighing 2,500 pounds or less to $1.25 per 100 pounds for those weighing over 6,000 pounds. In California there was a flat fee of $3, to which were added fees ranging up to $50 for the heaviest weights permitted for 4-wheel trucks. Those weighing less than 3,000 pounds paid only the flat fee.

NATIONAL FIGURES FOR TRUCKS FOR 1932 SHOWN

National totals, averages, and percentages for trucks and tractor trucks, and for trailers and semitrailers, are given in table 7. The tabulation includes, for each capacity group, the number registered and tax paid and total and average payments of gasoline taxes, registration fees, special fees (without averages), and all fees and taxes. The percentage distribution of numbers registered and fees paid among the several capacity groups is also given.

The total number of freight-carrying vehicles registered in 1932 was 3,644,591, or 14.80 percent of all vehicles registered and tax-paid in that year. The total of all State fees and taxes paid by these vehicles was $203,866,943, or 25.12 percent of all payments charged directly against motor vehicles in 1932.

Of all trucks and tractor trucks registered in 1932, 83.05 percent were light-weight vehicles, having rated capacities of 1½ tons or less. The percentage decreases steadily with the size of vehicle, except for the last bracket group, which contains all trucks of more than 5 tons capacity.

In the payments of fees and taxes the percentages were much different. Five-ton trucks and tractor trucks, which constituted only 0.88 percent of those registered, accounted for 1.54 percent of the gasoline taxes and 3.91 percent of the registration fees paid in 1932 by all trucks and tractor trucks.[4] Those of more than 5 tons capacity, which included only 1.37 percent of the vehicles, contributed 4.41 percent of all State fees and taxes paid by trucks.

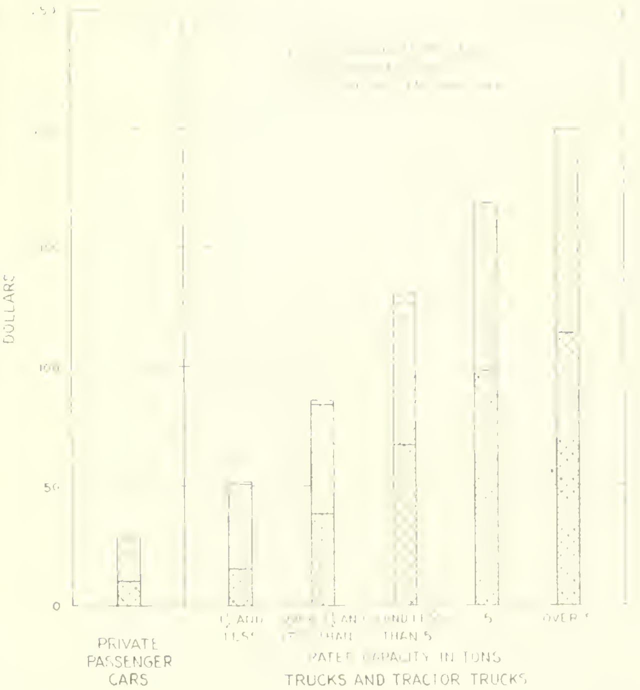
This variation of fee payments with capacity is shown more clearly by the averages given in table 7. Average registration fees varied from $16 in the lowest capacity group to $114 paid by those of more than 5 tons capacity; and average gasoline-tax payments ranged from $36 to $81.

Similar relations are shown in the trailer payments. The fees imposed on trailers are, in the majority of States, considerably less than those imposed on trucks. This is particularly true in the case of very light trailers, as is shown by the fact that those having capacities of 1½ tons or less paid average registration fees of only $3.34. However, there is a sharp rise in average payments with capacity, until we find those of more than 5 tons capacity charged with average registration fees of $71, and total payments of $92.

The excess registration fees of $500,807, paid by contract and common carriers, and the special fees of $2,585,161, which were also, for the most part, the contribution of for-hire carriers, play no great part in the total payments by trucks and trailers. They are included in table 7 to complete the record, and are taken up in detail in the section dealing with contract and common carriers.

DISTRIBUTION OF TRUCKS BY CAPACITY GROUPS

In table 8 all trucks and tractor trucks and trailers and semitrailers registered in each State in 1932 are listed by capacity groups. While this table is useful chiefly for reference purposes, certain significant facts may be gleaned from it. Of particular interest is the distribution of trucks by capacity in different States and in the several regional groups. In those States which are predominantly rural the percentage of light trucks was very high, and there were relatively few having capacities of 3 tons or more. In seven States, Vermont, South Carolina, North Dakota, South Dakota, Tennessee, Montana, and Wyoming, none had a capacity of more than 5 tons. Five-ton trucks were found in all States, but the number was 20 or less in South Carolina, Georgia, North Dakota, South Dakota, Alabama, Arkansas, Wyoming, and New Mexico.



Comparison of Average Payments of State Fees and Taxes in 1932 by Private Passenger Cars and by Trucks and Tractor Trucks of Different Rated Capacities.

COMPARISONS RELATING TO THE NUMBERS OF HEAVY TRUCKS AND THE FEES IMPOSED

In the complete report considerable space is devoted to a discussion of the relative numbers and percentages of heavy trucks registered in different States, and to consideration of the question whether or not the imposition of high registration fees upon such vehicles, particularly when accompanied by high gasoline tax rates, tends to discourage the registration of such vehicles and, in consequence, to reduce the revenues derived from them. It is not possible, in this short digest, to reproduce this discussion, but we may set down the main points established, with sufficient illustrative material to indicate the trend of the analysis.

1. As would be expected, the dominant factor determining the relative numbers or percentages of heavy trucks registered in different States is the comparative industrial and commercial development of the States concerned. The highly developed States of the East, the Middle West, and the Pacific coast have many heavy trucks. Relatively few are found in the Northwestern and Mountain States and in most of the States of the South, although in a few of the sparsely populated States, such as Nevada, the percentage of heavy trucks is high.

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[4] Unless otherwise specified the word "trucks", when used subsequently in this discussion, refers to trucks and tractor trucks.

TABLE 7.—*State taxes imposed on freight vehicles in 1932: national totals, averages, and percentages*

Rated capacity	Number registered	Percentage distribution	Estimated payments of motor-fuel taxes			Regular registration fees [1]		
			Amount	Average per vehicle	Percentage distribution	Amount collected	Average per vehicle	Percentage distribution
Tons								
Trucks and tractor trucks:								
1½ and less	2,681,985	83.05	$96,990,409	$36.16	76.64	$41,353,370	$15.42	58.43
Over 1½ and less than 3	341,285	10.57	15,812,494	46.33	12.49	12,953,474	37.96	18.30
3 and less than 5	128,938	3.99	7,721,581	59.89	6.10	8,601,940	66.71	12.15
5	28,544	.88	1,943,828	68.10	1.54	2,771,781	97.11	3.92
Over 5	44,056	1.37	3,573,972	81.12	2.82	5,013,807	113.81	7.09
Total classified	3,224,808	99.86	126,042,284	39.09	99.59	70,694,372	21.92	99.89
Not classified by capacity	4,507	.14	519,385	115.24	.41	77,657	17.23	.11
Other undistributed fees [4]						2,518		.00
Total	3,229,315	100.00	126,561,669	39.19	100.00	70,774,547	21.92	100.00
Trailers and semitrailers:								
1½ and less	326,183	78.55				1,083,073	3.32	31.44
Over 1½ and less than 3	25,705	6.19				344,698	13.41	10.01
3 and less than 5	23,781	5.73				837,210	35.20	24.30
5	6,372	1.53				364,700	57.23	10.59
Over 5	8,714	2.10				610,539	70.06	17.72
Total classified	390,755	94.10				3,240,220	8.29	94.06
Not classified by capacity	24,521	5.90				204,539	8.34	5.94
Total	415,276	100.00				3,444,759	8.30	100.00
All freight vehicles	3,614,591		126,561,669	39.19		74,219,306	20.36	

Rated capacity	Excess registration fees [1]	Total registration fees [1]			Special fees and taxes [2]	All fees and taxes		
		Amount collected	Average per vehicle	Percentage distribution		Amount	Average per vehicle	Percentage distribution
Tons								
Trucks and tractor trucks:								
1½ and less	$246,581	$41,599,951	$15.51	58.42	$457,634	$139,047,994	$51.85	69.68
Over 1½ and less than 3	86,861	13,040,335	38.21	18.32	471,473	29,324,302	85.92	14.69
3 and less than 5	79,873	8,681,813	67.33	12.19	410,432	16,813,826	130.40	8.43
5	13,371	2,785,152	97.57	3.91	80,494	4,809,474	168.49	2.41
Over 5	3,535	5,017,342	113.89	7.05	202,220	8,793,534	199.60	4.41
Total classified	430,221	71,124,593	22.06	99.89	1,622,253	198,789,130	61.64	99.62
Not classified by capacity [3]		77,657	17.23	.11	3,046	600,088	133.15	.30
Other undistributed fees [4]		2,518			165,568	168,086		.08
Total	430,221	71,204,768	22.05	100.00	1,790,867	199,557,304	61.80	100.00
Trailers and semitrailers:								
1½ and less	6,621	1,089,694	3.34	31.00	27,478	1,117,172	3.42	28.14
Over 1½ and less than 3	17,333	362,031	14.08	10.30	39,776	401,807	15.63	10.12
3 and less than 5	29,774	866,984	36.46	24.66	125,028	992,012	41.71	24.99
5	12,613	377,313	59.21	10.73	64,401	441,714	69.32	11.12
Over 5	4,245	614,784	70.55	17.49	189,954	804,738	92.35	20.27
Total classified	70,586	3,310,806	8.47	94.18	446,637	3,757,443	9.62	94.64
Not classified by capacity		204,539	8.34	5.82		204,539	8.34	5.15
Other undistributed fees [4]					8,377	8,377		.21
Total	70,586	3,515,345	8.46	100.00	455,014	3,970,359	9.56	100.00
Undistributed freight-carrier fees [5]					339,280	339,280		
All freight vehicles	500,807	74,720,113	20.50		2,585,161	203,866,943	55.94	

[1] In a number of States contract and common carriers of property were required to pay higher registration fees than private carriers. "Regular registration fees" include actual payments of private carriers and the estimated payments of contract and common carriers based on the private carrier rates. "Excess registration fees" include all payments of contract and common carriers in excess of the estimated payments at the private carrier rates. "Total registration fees" are total actual payments by all classes of carriers.

[2] Includes all special fees and taxes, paid principally by contract and common carriers, such as mileage taxes, receipts taxes, franchise fees, privilege taxes, and other miscellaneous special fees. Excess registration fees are not included.

[3] All unclassified were tractor trucks. The payments by these vehicles could not logically be distributed among the several capacity groups.

[4] The term "Other undistributed fees" refers to payments which could not properly be assigned to a specific number of vehicles and therefore could not be distributed among the several capacity groups. Also included are payments of special fees by contract-carrier trucks in Montana, Oklahoma, and South Dakota, $80,701; and special fees of common-carrier trucks in South Dakota, $36,971. The numbers of these trucks were given, but their registration fees were not segregated from those of private carriers, and they were not classified by weight or capacity.

[5] Special fees applicable to both trucks and trailers, which could not be allocated by reasonable methods of approximation.

2. Limitations imposed on gross loads undoubtedly have an effect on the registration of heavy trucks, particularly those of more than 5 tons capacity. However, in a number of the States reporting few heavy trucks, including Alabama, Georgia, Kansas, Montana, North Dakota, Virginia, and Wyoming, the load restrictions were liberal, particularly with respect to six-wheel trucks.

3. In certain populous States registration fees of considerable magnitude have not apparently discouraged the registration of heavy trucks. Thus, in Iowa, where registration fees of $250 were required for 5-ton trucks, and $350 for 7-ton trucks, the total collections from trucks and tractor trucks of 5 tons capacity or more were $46,634. In Wisconsin, where the fees for these two classes [5] were $210 and $310, respectively, the collections were $224,551. These rates, however, are low compared to those in effect in certain other States.

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[5] Fees computed on basis of conversion between gross weight and capacity; see table 4.

TABLE 8.—*State totals of freight vehicles registered and regular fees paid in 1932; grouped according to rated capacity*

Division and State	Trucks and tractor trucks							Trailers and semitrailers						
	Rated capacity in tons							Rated capacity in tons						
	1½ and less	Over 1½ and less than 3	3 and less than 5	5	Over 5	Not classified by capacity [1]	Total	1½ and less	Over 1½ and less than 3	3 and less than 5	5	Over 5	Not classified by capacity	Total
New England	**191,983**	**22,159**	**13,479**	**2,489**	**3,726**	**817**	**234,653**	**7,000**	**247**	**252**	**84**	**654**	**139**	**8,376**
Maine	31,519	2,870	1,430	195	143	46	36,203	3,997					139	4,136
New Hampshire	14,025	1,698	1,445	203	7		17,378	1,153	48	47	34	4		1,286
Vermont	6,780	906	548	75			8,309	473	3	3				479
Massachusetts	81,751	10,966	6,534	907	2,030	771	102,959	218	136	162	48	523		1,117
Rhode Island	15,124	1,086	1,089	166	651		18,416	18	11	13	1	25		68
Connecticut	42,484	4,633	2,433	943	895		51,388	1,111	49	27	1	102		1,290
Middle Atlantic	**501,495**	**137,094**	**41,934**	**15,363**	**28,134**	**162**	**727,182**	**11,713**	**5,329**	**2,752**	**1,238**	**2,842**	**3,038**	**26,912**
New York	216,555	64,564	14,413	6,867	11,366		313,765	5,559	4,298	1,078	170	2,683		13,788
New Jersey	89,916	18,781	10,083	1,616	8,208		128,604						3,038	3,038
Pennsylvania	144,554	15,653	12,515	5,773	7,743	96	216,334	4,549	862	1,305	826	13		7,555
Delaware	6,884	888	525	188	181		8,666	555	50	28	10	31		674
Maryland	34,743	3,712	2,245	620	207		41,527	719	99	243	215	35		1,311
District of Columbia	11,843	3,496	2,153	299	429	66	18,286	331	20	98	17	80		546
South Atlantic	**224,538**	**13,818**	**6,262**	**540**	**91**		**245,249**	**17,847**	**2,082**	**1,697**	**301**	**92**	**3,750**	**25,769**
Virginia	58,379	2,982	904	73	6		62,344	1,800	175	302	112	1		2,390
West Virginia	29,536	1,538	1,640	189	13		32,916	1,391	221	23	6	20		1,661
North Carolina	43,242	4,175	2,599	207	39		50,262	6,692	837	611	86	39		8,265
South Carolina	18,341	1,021	354	3			19,722	809	541	483	45	32		1,910
Georgia	39,665	1,934	430	20	1		42,050	147	65	18	11		3,750	4,021
Florida	35,375	2,165	335	48	32		37,955	7,008	243	230	41			7,522
East North Central	**591,016**	**71,247**	**24,606**	**5,120**	**4,810**	**1,852**	**698,654**	**141,895**	**4,749**	**7,014**	**1,145**	**1,972**		**157,075**
Ohio	137,880	20,345	7,940	501	826		167,492	40,816	1,268	2,603	335	576		45,598
Indiana	113,370	4,850	1,766	117	64	1,852	122,019	21,435	913	792	142	261		23,543
Illinois	145,083	18,577	8,845	3,482	1,833		177,820	7,552	811	227	41	272		8,903
Michigan	96,169	21,743	3,321	638	1,402		123,273	71,961	1,398	3,016	789	374		77,538
Wisconsin	98,514	5,732	2,734	382	685		108,047	131	359	376	138	489		1,493
West North Central	**408,507**	**24,361**	**9,161**	**804**	**168**		**443,001**	**40,168**	**1,594**	**1,557**	**1,017**	**697**	**13,478**	**58,811**
Minnesota	95,877	3,871	1,570	282	50		101,650	20,298	409	440	210	172		21,529
Iowa	63,511	9,024	2,162	99	86		74,882	2,369	145	205	64	91		2,874
Missouri	88,668	6,315	3,911	343	28		99,265	7,647	601	648	694	118		10,008
North Dakota	22,957	471	156	6			23,590	19	3	14	2	1		39
South Dakota	18,581	789	168	4			19,542	8,800	46	5	1			8,852
Nebraska	49,636	1,983	630	42	3		52,294						13,478	13,478
Kansas	69,277	1,908	564	28	1		71,778	1,335	390	245	46	15		2,031
East South Central	**112,139**	**4,946**	**2,130**	**162**	**19**	**398**	**119,794**	**4,497**	**581**	**590**	**100**	**21**	**4,056**	**9,848**
Kentucky [2]	28,845	1,957	753	58	8		31,621							
Tennessee	29,152	1,322	500	72		388	31,434	2,258	438	491	86	21		3,294
Alabama	30,228	1,052	277	7	1	10	31,575						4,056	4,056
Mississippi	23,914	615	600	25	10		25,164	2,239	146	99	14			2,498
West South Central	**259,558**	**29,120**	**9,856**	**1,177**	**307**	**1,170**	**301,188**	**32,841**	**5,952**	**5,816**	**842**	**174**		**45,595**
Arkansas	22,068	775	143	2	1		22,989	2,145	285	428	146			3,004
Louisiana	37,791	2,159	628	72	33	1,170	41,853	3,281	1,308	1,685	219			6,493
Oklahoma [3]	38,628	4,321	1,576	326	33		44,884							
Texas	161,071	21,865	7,509	777	240		191,462	27,415	4,359	3,703	447	174		36,098
Mountain	**115,478**	**7,728**	**3,007**	**502**	**316**	**56**	**127,417**	**12,938**	**510**	**428**	**91**	**108**	**60**	**14,135**
Montana	19,514	776	203	28			20,521						60	60
Idaho	12,417	1,176	365	50	22		14,030	9,912	73	60	10			10,055
Wyoming	9,163	476	230	10			9,879	12	1	4	1			18
Colorado	27,368	2,286	514	109	24	56	30,357	225	197	126	23	13		584
New Mexico	14,354	489	160	15	2		15,020	500	71	38	6	4		619
Arizona	12,851	1,049	521	102	164		14,687	1,490	130	127	38	71		1,856
Utah	13,980	1,159	731	134	92		16,096	221	30	59	12	3		325
Nevada	5,831	317	283	54	42		6,527	578	8	14	1	17		618
Pacific	**274,271**	**30,812**	**18,503**	**2,387**	**6,455**	**52**	**332,480**	**56,984**	**4,658**	**3,675**	**1,284**	**2,154**		**68,755**
Washington	52,337	6,845	3,279	456	909		63,826	3,617	182	245	14	208		1,296
Oregon	27,224	4,307	1,502	286	1,158		34,477	797	283	343	85	198		1,706
California	194,710	19,660	13,722	1,645	1,388	52	234,177	52,570	4,193	3,087	1,155	1,748		62,753
Grand total	2,681,985	341,285	128,938	28,541	44,056	1,507	3,229,315	326,183	25,705	23,781	6,372	8,714	24,521	445,276

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[1] In all cases, these vehicles are unclassified tractor trucks.

[2] Full trailers prohibited. Semitrailers registered with tractor trucks.

[3] No registration of trailers or semitrailers in 1932.

4. In those States which imposed unusually high registration fees on heavy trucks the number of such vehicles was almost invariably small and the revenues correspondingly low. This was particularly true in a number of Southern States in which high registration fees were combined with high gasoline taxes.

In Georgia, for example, the rates for trucks of over 5 tons capacity were as follows: 6 tons, $375; 7 tons, $750; over 7 tons, $1,125. Against this imposing array of fees we find but one truck of more than 5 tons capacity registered in 1932—a 6-ton truck, paying $375.

In North Dakota, where the rate on 5-ton trucks was $400 and on those over 5 tons, $600 to $1,500, with reductions after the first year of registration, we find six 5-ton trucks paying a total of $1,404, and none over 5 tons. In South Dakota, where the schedule of rates, based on chassis weights, was also very high, only four 5-ton trucks were registered, with total collections of $1,300.

One apparent effect of high registration fees was to bring about the registration of heavy trucks for only a part of the year. In Alabama only one truck of more than 5 tons capacity was registered, a 6-ton truck paying $187.50, or one-fourth the annual fee of $750. In Arkansas, similarly, one 6-ton truck paid $100, the annual rate being $400. In Texas a rate of $4 per hundredweight applied to trucks having gross weights of 26,000 pounds or more was apparently not productive, as the average payment reported for trucks of more than 5 tons capacity was only $144.23.

In Louisiana the law provided that trucks with a net carrying capacity greater than 5 tons should be charged $150 for each thousand pounds carrying capacity in excess of 5 tons, in addition to a fee of 68 cents per horsepower and $32 per ton for the first 5 tons ($50 per ton for common carriers). City trucks were exempted from this schedule and paid at the rate of $10 per ton plus 68 cents per horsepower. No private trucks were reported as paying the high rates cited above. Five common carriers having capacities of more than 5 tons paid a total of $323. Of city trucks there were 28 of more than 5 tons capacity and the total collections from them were $3,050. Thus we have a relatively low rate of registration fee producing nearly 10 times the revenue obtained from a very high rate applied to vehicles of the same capacity group.

The conclusion is inescapable that such unusually high rates, if effective at all, succeed only in discouraging or virtually prohibiting the registration of heavy vehicles. A more logical procedure in devising a schedule of registration fees for a given State would seem to be, first, to fix definitely the maximum load to be permitted on the roads, and then to adjust the scale of fees with a view of obtaining a maximum yield. It is a recognized principle that heavy vehicles should pay the additional costs of highways designed to support their loads, so far as those costs can be determined. It is not always realized that one of the variables entering into the computation is the number of such vehicles which may be registered in a State. Laws which impose exorbitant fees on heavy trucks tend to defeat the purpose for which they were enacted, if that purpose was to increase the income of the State.

5. In a comparison of the registration of heavy trucks with the mileage of high-type State highways it was found that in a number of the States having very low registrations in this class of vehicles, there are considerable mileages of high-type road, and particularly of portland-cement concrete. Conspicuous examples of this situation are shown in table 9.

One could hardly say that the 1,922 miles of concrete road in South Carolina were built primarily to accommodate the three 5-ton trucks which were registered, or even the 357 trucks which had capacities of 3 tons or more. Similarly, in Alabama, Arkansas, Georgia, and even in Indiana, the number of such trucks is so small as to be a negligible factor in the traffic on the high-type roads. It should also be remembered that a large proportion of the movement of heavy trucks takes place within the limits of cities.

TABLE 9.—*Comparison of heavy trucks registered with mileage of high-type State highways existing in 1932*

State	Number of trucks of 5 tons capacity or more	High-type State highways[1] in 1932	
		All high-type	Portland cement concrete
Alabama	8	1,049	730
Arkansas	3	2,002	1,032
Florida	80	1,398	528
Georgia	21	1,747	1,035
Indiana	181	4,174	3,430
Kentucky	66	1,627	736
Louisiana	105	2,041	1,795
South Carolina	3	2,370	1,922
Tennessee	72	2,251	1,190

[1] From annual table published by the Bureau, "State highway mileage existing in 1932."

Very different relations are shown if we take certain other States, such as New York, with 18,233 trucks of 5 tons or more capacity, and 10,716 miles of high-type State highways; Wisconsin, with 1,067 such trucks and 4,138 high-type miles; or Wyoming, with 240 trucks of 3 tons or more capacity, 10 of 5 tons or more, and 35 miles of high-type surface. Nevertheless, the inference is very clear that concrete and other high-type surfaces are constructed primarily in response to the present and anticipated demands of the motoring public in general, rather than specifically to support the traffic of heavy trucks.

FOR-HIRE CARRIERS OF PROPERTY

The analysis of the reports submitted in this survey and of laws in effect in 1932 indicates that for-hire carriers of property were, in one way or another, recognized as separate classes of vehicles in all States except Maine, New Hampshire, Connecticut, New York, New Jersey, Delaware, the District of Columbia, and Nebraska. Laws were passed in Maine and New Hampshire providing for the regulation of for-hire carriers in 1933.

A number of States which have such regulations failed to report separately the numbers of for-hire vehicles or their payments of fees; these States were Rhode Island, Pennsylvania, Indiana, Illinois, Tennessee, and Mississippi. In all, 35 States reported for-hire carriers in such a manner that they could be included in the tabulations of national totals, percentages, and averages.

The statisticians for each State were requested to report contract carriers and common carriers separately. This could not be done in all cases, because of the lack of uniformity among the States in the classes into which property carriers are divided. Some States recognize and regulate only one class of for-hire carriers, while others have three or more. There is no universally accepted definition of a common carrier, and it was necessary in a number of cases to exercise judgment as to the class to which a given group of vehicles should be assigned. It was decided to regard the term "contract carrier" as the more general classification, and to include in that group all for-hire carriers other than those definitely assignable to the common-carrier class. Where contract and common carriers were reported together, they were assigned to the contract group. This was done in the case of three States, Arkansas, Ohio, and West Virginia, and probably in the case of Massachusetts, which reported only contract carriers.

Contract-carrier trucks were reported in 26 States, and contract-carrier trailers in 20 States. Thirty-one States reported common-carrier trucks and 24 States reported common-carrier trailers. A segregation of for-hire property carriers into contract and common was available for trucks in 22 States and for trailers in 16 States.

The tabulation of contract carriers also includes a small number of private carriers operating in commercial service and subject to special taxation.

SPECIAL TAXATION IMPOSED ON FOR-HIRE CARRIERS IN MAJORITY OF STATES

Of the 41 States which recognized for-hire carriers of property as a special class of vehicle, all but five—Vermont, Massachusetts, Rhode Island, Indiana, and Illinois—imposed higher taxes in 1932 upon contract or common carriers, or both, than those which privately operated carriers were required to pay, although in a few States certain classes of private carriers were included in the increased taxation. In some States the increase took the form of higher registration fees; in other States special fees, such as have been described in the case of public-carrier busses, were imposed.

Excess registration fees.—Registration fees in excess of the private-carrier rate were paid by contract-carrier trucks in Florida, Idaho, North Carolina, North Dakota, South Carolina, Virginia, and West Virginia. Higher rates were also paid by for-hire carriers in Arkansas, which reported contract and common carriers together. In Arkansas and Florida special fees were paid in addition to the excess registration fees. In Massachusetts, Minnesota, and Missouri contract carriers paid registration fees at the private-carrier rate, and no special fees.

Common-carrier trucks paid excess registration fees in the following States: Florida, Idaho, Louisiana, Minnesota, North Carolina, and North Dakota. Additional special fees were paid in all these States except Louisiana.

In Maryland, South Carolina, and West Virginia, common carriers were not required to pay registration fees, ton-mile taxes being assessed in lieu thereof. In California common carriers paid a receipts tax and no registration fees. In New Mexico the rate of registration fee on common carriers was one-half the private rate.

Mileage taxes.—Taxes based on mileage traveled were imposed on contract carriers of property in Florida, Georgia, Kentucky, and Oklahoma; and on common carriers in Alabama, Florida, Georgia, Kentucky, New Mexico, and Oklahoma. In Tennessee and Mississippi for-hire carriers and certain classes of private carriers were required to pay a mileage tax. In Oklahoma class C motor carriers (private carriers who make a charge for the delivery of goods) were also required to pay a mileage tax.

In all these States except Oklahoma the rate per mile increased with the weight or capacity of the vehicle. In Alabama, for example, the rates varied from ½ cent per mile for vehicles under 2 tons capacity to 2 cents per mile for trucks of 5 tons capacity or more. In New Mexico the rates varied from ¼ cent per mile for vehicles of 1½ tons capacity or less to 3 cents per mile for vehicles of more than 5 tons capacity. In Oklahoma the rate was ½ cent per mile for contract and class C carriers, and ⅔ cent per mile for common carriers.

Ton-mile taxes.—Ton-mile taxes were imposed on contract carriers of property in Colorado, Kansas, Utah, Wisconsin, and Wyoming, and on common carriers in Colorado, Iowa, Kansas, Maryland, Oregon, South Carolina, Utah, West Virginia, Wisconsin, and Wyoming. In Wisconsin and Kansas certain classes of private carriers were also required to pay a ton-mile tax.

In 3 States—Wyoming, Colorado, and Utah—the rates were based on revenue ton-miles, that is, the sum of the products of all revenue cargoes times the miles each cargo was carried. The rate in Wyoming was 1/5 cent per ton-mile; in Colorado, 1/2 cent; and in Utah, 2/3 cent on hard-surfaced roads and 1/4 cent on other roads.

In West Virginia the ton-mile tax on common carriers was based on the capacity of the vehicle times the scheduled mileage. In the remaining States the gross ton-mile was the basis of the tax. Of these States, the law in Iowa and Oregon stipulated that the gross weight used should include the weight of the vehicle and its maximum load. In Kansas the gross weight included the weight of the vehicle plus twice its capacity load. In Maryland, South Carolina, and Wisconsin, the rated capacity was added to the weight of the vehicle in computing the tax.

The rates charged per ton-mile in these States varied from 1/20 cent in Kansas to ½ cent charged in South Carolina against trucks having gross weights of more than 7 tons.

Receipts taxes.—Taxes on gross receipts were imposed on contract carriers of property only in Arkansas, which reported contract and common carriers together, and in Pennsylvania, which imposed the tax on all for-hire vehicles, but did not segregate for-hire carriers of property from other carriers. Receipts taxes were imposed on common carriers in Arizona, California, Idaho, North Carolina, South Dakota, Virginia, and Washington. In North Carolina the payments of registration fees were credited against the gross receipts tax, and in California the receipts tax was in lieu of registration fees. The rates paid in these nine States varied from 0.8 percent in Pennsylvania to 6 percent in North Carolina.

Other special fees.—Fees for the issuance of certificates of convenience and necessity, or equivalent permits, were paid by both contract and common carriers in Colorado, Georgia, Kentucky, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming; and by common carriers only in Alabama, Minnesota, North Dakota, and Wisconsin. Franchise or permit fees at flat rates per vehicle were assessed on both contract and common carriers in Georgia, Montana, Texas, and Wisconsin, on contract carriers in Iowa, and on for-hire carriers operating as transfer companies in Tennessee. Franchise or special license fees increasing with the weight or capacity of the vehicle were paid by contract and common carriers in Michigan, Ohio, and Nevada; by contract carriers only in Oregon and South Dakota; and by common carriers only in Missouri, Oklahoma, and Tennessee.

ONLY A PART OF ALL FOR-HIRE CARRIERS REPORTED

In all, there were reported 96,670 for-hire carriers of property, consisting of 87,825 trucks and 8,845 trailers and semitrailers. The tabulation of these vehicles by class of service is as follows:

For-hire trucks and tractor trucks:	
Contract-carrier	70, 956
Common-carrier	16, 869
For-hire trailers and semitrailers:	
Contract-carrier	5, 008
Common-carrier	3, 837

TABLE 10.—*State taxes imposed on contract carriers of property in 1932; national totals and averages*

REGISTRATION FEES AND MOTOR-FUEL TAXES

Rated capacity	Number registered	Estimated payments of motor-fuel taxes		Regular registration fees			Excess registration fees			Total registration fees			Total registration fees and motor-fuel taxes		
		Amount	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle
Tons															
Trucks and tractor trucks:															
1½ and less	45,306	$2,412,710	$53.25	45,306	$855,760	$18.89	14,043	$223,161	$15.89	45,306	$1,078,921	$23.82	45,306	$3,491,631	$77.0
Over 1½ and less than 3	14,613	996,516	68.20	14,613	601,485	41.16	2,341	67,552	28.86	14,613	669,037	45.78	14,613	1,665,553	113.9
3 and less than 5	7,794	690,141	88.55	7,794	525,591	67.44	1,962	62,635	31.92	7,794	588,226	75.47	7,794	1,278,367	164.0
5	800	90,225	112.78	800	74,595	93.24	176	10,316	58.61	800	84,911	106.14	800	175,136	218.9
Over 5	1,303	169,493	130.08	1,303	114,206	87.65	23	2,006	87.22	1,303	116,212	89.19	1,303	285,705	219.2
Total classified	69,816	4,359,085	62.44	69,816	2,171,637	31.11	18,545	365,670	19.72	69,816	2,537,307	36.34	69,816	6,896,392	98.7
Not classified by capacity [1]	24	2,142	89.25	24	382	15.92				24	382	15.92	24	2,524	105.1
Not segregated [2]	1,116	80,254	71.91	1,116	31,418	28.15				1,116	31,418	28.15	1,116	111,672	100.0
Undistributed fees [3]					2,518						2,518			2,518	
Total	70,956	4,441,481	62.59	70,956	2,205,955	31.09	18,545	365,670	19.72	70,956	2,571,625	36.24	70,956	7,013,106	98.8
Trailers and semitrailers:															
1½ and less	1,411			1,111	10,399	9.36	526	4,837	9.20	1,111	15,236	13.71			
Over 1½ and less than 3	943			943	18,953	20.10	523	14,390	27.51	943	33,343	35.36			
3 and less than 5	1,847			1,847	81,085	43.90	578	22,399	38.75	1,847	103,484	56.03			
5	485			485	28,113	57.96	161	6,307	39.17	485	34,420	70.97			
Over 5	622			622	40,457	65.04	9	1,937	215.22	622	42,394	68.16			
Total	5,008			5,008	179,007	35.74	1,797	49,870	27.75	5,008	228,877	45.70			

SPECIAL FEES

Rated capacity	Mileage or ton-mile taxes			Receipts taxes			Franchise fees, certificate fees, and other miscellaneous special fees			Total special fees and excess registration fees			All fees and taxes		
	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle
Tons															
Trucks and tractor trucks:															
1½ and less	1,073	$25,767	$24.01	888	$17,789	$20.03	10,438	$170,021	$16.29	24,591	$436,738	$17.76	45,306	$3,705,208	$81.7
Over 1½ and less than 3	706	36,149	51.20	225	6,845	30.42	7,350	173,468	23.60	9,727	284,014	29.20	14,613	1,882,015	128.7
3 and less than 5	333	28,494	85.57	43	1,962	45.63	3,106	136,055	43.80	5,104	229,146	44.90	7,794	1,444,878	185.3
5	57	4,134	72.53	1	73	73.00	289	18,504	64.03	471	33,027	70.12	800	197,847	247.3
Over 5	5	714	142.80				461	43,442	94.23	488	46,162	94.59	1,303	329,861	253.1
Total classified	2,174	95,258	43.82	1,157	26,669	23.05	21,644	541,490	25.02	40,381	1,029,087	25.48	69,816	7,559,809	108.2
Not classified by capacity [1]	10	825	82.50				10	7	.70	10	832	83.20	24	3,356	139.8
Not segregated [2]	647	67,330	104.06				1,116	13,371	11.98	1,116	80,701	72.31	1,116	192,373	172.3
Undistributed fees [3]							279	1,395	5.00	279	1,395	5.00		3,913	
Total	2,831	163,413	57.72	1,157	26,669	23.05	23,049	556,263	24.13	41,786	1,112,015	26.61	70,956	7,759,451	109.3
Trailers and semitrailers:															
1½ and less	43	965	22.44	125	1,837	14.70	311	1,828	5.88	837	9,467	11.31	1,111	19,866	17.8
Over 1½ and less than 3	45	1,317	29.27	59	2,109	35.75	231	3,139	13.59	754	20,955	27.79	943	39,908	42.
3 and less than 5	55	2,039	37.07	195	9,964	51.10	1,035	31,042	29.99	1,614	65,444	40.55	1,847	146,529	79.
5	5	97	19.40	93	6,833	73.47	216	9,580	44.35	377	22,847	60.52	485	50,930	105.
Over 5							245	11,315	46.18	254	13,252	52.17	622	53,709	86.
Total classified	148	4,418	29.85	472	20,743	43.95	2,038	56,904	27.92	3,836	131,935	34.39	5,008	310,942	62.
Undistributed fees [3]							76	380	5.00	76	380	5.00		380	
Total	148	4,418	29.85	472	20,743	43.95	2,114	57,284	27.10	3,912	132,315	33.82	5,008	311,322	62.

[1] See p. 191.
[2] See p. 191. Estimated payments of registration fees and gasoline taxes by these vehicles are included.
[3] See pp. 191 and 192.

These figures represent only a part of the total number of the property carriers in the United States operating as contract and common carriers in 1932. Thirty-five States are represented in the totals, but those which are omitted—Maine, New Hampshire, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, the District of Columbia, Indiana, Illinois, Nebraska, Tennessee, and Mississippi—include several of the most populous States in the Union. In view of this fact it would be hazardous to make an estimate of the total number of for-hire carriers operating in 1932. The validity of such an estimate would be further impaired by the fact that nine States reported common carriers but no contract carriers. The wide differences in State laws and regulations and the various classes o operation, such as city hauling and the hauling of far products, which are exempted in a number of State indicate that the totals obtained in this survey ar considerably below the total number of for-hire ca riers in the 35 States reporting such vehicles.

The National Code Authority for the truckin industry, operating under the National Recover Administration, is conducting a registration of vehicle engaged in the transportation of property for hir This registration is designed to show the number vehicles actually operating for hire, and not the numbe regulated by law. The registration was not complet at the time of preparation of this report. The tot

TABLE 11.—*State taxes imposed on common carriers of property in 1932: national totals and averages*

REGISTRATION FEES AND MOTOR-FUEL TAXES

Rated capacity	Number registered	Estimated payments of motor-fuel taxes		Regular registration fees			Excess registration fees			Total registration fees			Total registration fees and motor-fuel taxes		
		Amount	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle
Tons															
Trucks and tractor trucks.															
1½ and less	6,755	$411,732	$60.95	6,162	$114,395	$18.56	862	$23,120	$27.17	6,162	$137,815	$22.37	6,755	$549,517	$81.35
Over 1½ and less than 3	4,162	333,186	80.06	3,515	141,776	40.33	449	19,309	43.00	3,515	161,085	45.83	4,162	494,271	118.76
3 and less than 5	2,686	260,044	96.82	2,161	146,339	67.72	153	17,238	112.67	2,161	163,577	75.70	2,686	423,621	157.71
5	430	49,576	115.29	306	30,727	100.42	13	3,055	235.00	306	33,782	110.40	430	83,358	193.86
Over 5	640	90,707	141.73	393	52,087	132.54	3	1,529	509.67	393	53,616	136.13	640	141,323	225.50
Total classified	14,673	1,145,245	78.05	12,537	485,324	38.71	1,480	64,551	43.62	12,537	549,875	43.86	14,673	1,695,120	115.53
Not classified by capacity [1]	98	8,418	85.90	46	1,150	25.00				46	1,150	25.00	98	9,568	97.63
Not segregated [2]	2,098	101,762	18.50	2,098	49,901	23.79				2,098	49,901	23.79	2,098	151,663	72.29
Total	16,869	1,255,425	74.42	14,681	536,375	36.54	1,480	64,551	43.62	14,681	600,926	40.93	16,869	1,856,351	110.05
Trailers and semitrailers.															
1½ and less	452			358	4,629	12.93	147	1,781	12.14	358	6,413	17.91			
Over 1½ and less than 3	682			587	15,731	26.80	178	2,943	16.53	587	18,674	31.81			
3 and less than 5	1,378			1,168	51,448	46.62	155	7,375	47.58	1,168	61,823	52.93			
5	519			351	24,681	70.32	59	6,306	106.88	351	30,990	88.29			
Over 5	806			392	31,549	80.48	24	2,308	96.17	392	33,857	86.37			
Total	3,837			2,856	131,041	15.88	563	20,716	36.80	2,856	151,757	53.14			

SPECIAL FEES

Rated capacity	Mileage or ton-mile taxes			Receipts taxes			Franchise fees, certificate fees, and other miscellaneous special fees			Total special fees and excess registration fees			All fees and taxes		
	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount collected	Average per vehicle	Number of vehicles	Amount	Average per vehicle
Tons															
Trucks and tractor trucks:															
1½ and less	2,488	$119,994	$48.23	1,744	$47,494	$27.23	3,976	$76,539	$19.25	6,338	$267,447	$42.20	6,755	$793,574	$117.48
Over 1½ and less than 3	1,732	130,398	75.29	997	57,605	57.78	2,380	66,926	28.12	3,918	274,238	69.99	4,162	749,200	180.01
3 and less than 5	920	116,595	126.73	820	72,483	88.39	1,316	53,912	40.97	2,536	260,228	102.61	2,686	666,611	248.18
5	198	33,485	169.12	115	16,567	144.06	211	7,731	36.64	420	60,838	144.85	430	141,141	328.23
Over 5	260	79,552	305.97	289	69,738	241.31	112	7,931	70.81	634	158,750	250.39	640	301,544	471.16
Total classified	5,598	480,024	85.75	3,965	263,887	66.55	7,995	213,039	26.65	13,846	1,021,501	73.78	14,673	2,652,070	180.74
Not classified by capacity [1]	46	2,158	46.91				46	56	1.22	46	2,214	48.13	98	11,782	120.22
Not segregated [2]				2,098	23,471	11.19	2,098	13,500	6.43	2,098	36,971	17.62	2,098	188,634	89.91
Undistributed fees [3]	551	35,821	65.01				267	10,680	40.00	551	46,501	84.39		46,501	
Total	6,195	518,003	83.62	6,063	287,358	47.40	10,406	237,275	22.80	16,511	1,107,187	66.94	16,869	2,898,987	171.85
Trailers and semitrailers:															
1½ and less	204	12,043	59.03	209	6,775	32.42	164	4,030	24.57	422	24,632	58.37	452	29,261	64.74
Over 1½ and less than 3	235	12,345	52.53	260	13,928	53.57	360	6,938	19.27	652	36,154	55.45	682	51,885	76.08
3 and less than 5	256	15,402	60.16	416	34,851	83.78	819	31,730	38.74	1,309	89,358	68.26	1,378	143,806	104.36
5	40	4,915	122.88	215	27,431	127.59	228	15,545	68.18	456	54,197	118.85	519	78,881	151.99
Over 5	156	33,987	217.87	485	130,032	268.11	224	14,620	65.27	785	180,947	230.51	806	212,496	263.64
Total classified	891	78,692	88.32	1,585	213,017	134.40	1,795	72,863	40.59	3,624	385,288	106.32	3,837	516,329	134.57
Undistributed fees [3]	154	7,227	46.93				154	770	5.00	154	7,997	51.93		7,997	
Total	1,045	85,919	82.22	1,585	213,017	134.40	1,949	73,633	37.78	3,778	393,285	104.10	3,837	521,326	135.65

[1] See p. 191. [2] See p. 191. Estimated payments of registration fees and gasoline taxes by these vehicles are included. [3] See pp. 191 and 192.

reported as of September 21, 1934, was 244,573. This is the figure for load-carrying vehicles, i.e., trucks, trailers, and semitrailers, but not tractor trucks.[6]

PAYMENTS BY PROPERTY CARRIERS ANALYZED

National totals and averages for contract and common carriers of property are given in tables 10 and 11, respectively. Certain items in these tables require explanation. In order to emphasize the fact that certain States exact higher registration fees from for-hire carriers than from those privately owned and operated, the excess payments in those States have been tabulated separately. Total payments of registration fees, however, are also given. In order to show the total amounts paid in additional fees, special fees and excess registration fees are tabulated together under the heading "Total special fees and excess registration fees".

In table 1 and in the discussion on page 191, attention was called to a group of contract and common carriers in Montana, Oklahoma, and South Dakota, which were not segregated from private carriers, although their payments of special fees were given separately. In tables 10 and 11 these vehicles are tabulated separately; and estimates have been made of their payments of gasoline taxes and registration fees on the basis of the average payments by other classes of trucks in Montana, Oklahoma, and South Dakota.

The special fees tabulated do not include all payments of such fees by for-hire carriers. Among the payments which could not be properly allocated were receipts taxes paid by all for-hire carriers in Pennsylvania, ton-mile taxes paid by for-hire carriers and certain classes of private carriers in Kansas, mileage taxes and privilege taxes in Tennessee, and certificates fees in Texas and New Mexico.

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[6] A.T.A. Registration Bulletin, Sept. 21, 1934; published by the American Trucking Association.

Payments of registration fees and special fees by for-hire carriers in the individual States will be found in tables 14 and 15, where all such payments are tabulated. A few examples of average payments in different States will serve to illustrate the range in charges against for-hire carriers.

Contract carriers.—Average payments of registration fees by contract-carrier trucks ranged from $10.24 in Virginia to $89 in Ohio. Average payments of all fees and taxes varied from $55 in Missouri to $256 in Nevada. As in the case of privately operated trucks, the average payments in most States increased rapidly with the size of the vehicle. Thus, average payments of registration fees by trucks of 1½ tons capacity and less varied from $8.79 in Virginia to $41 in Oregon. For trucks of more than 5 tons capacity the range was from $35 in Massachusetts to $313 in Iowa. For all fees and taxes, payments in the light-tonnage group varied from $42 in Missouri to $214 in Florida, and those in the heavy-tonnage group from $163 in Massachusetts to $759 in Kentucky.

Common carriers.—Average payments of registration fees by common-carrier trucks varied from $13.56 in Missouri to $84 in Oregon; and of all fees and taxes, from $99 in Missouri to $445 in Florida. The range of average payments by trucks of 1½ tons capacity and less was as follows: in registration fees, from $10.50 in Missouri to $47 in Idaho; in all fees and taxes, from $70 in Colorado to $408 in Florida. In the case of the heaviest capacity group (5 tons or more) registration fees varied from $33 in Missouri to $337 in Iowa, and all fees and taxes from $276 in Louisiana to $1,031 in Minnesota.

COMPARISON OF FEES REQUIRED FOR TYPICAL COMMON-CARRIER TRUCK OPERATION

The average payments by common carriers, as reported, do not accurately reflect the differences in tax rates among the States. Even if the bases and rates of taxation were the same for all States, average payments would vary because of such factors as differences in the frequency of part-year registrations, average mileage traveled, the volume of business, and the proportion of light and heavy trucks.

A few examples of the total legal payments required of a typical common-carrier truck operating under a given set of conditions will serve to illustrate the extreme range in taxation. In this computation we assume a truck of 5 tons capacity, operating 15,000 miles per year. Table 4 gives the net weight of such a truck as approximately 11,700 pounds and the gross weight as 21,700 pounds. The assumed gasoline consumption, at 5 miles per gallon, is 3,000 gallons. Comparative figures have been computed for the States of Florida, Michigan, Kansas, and New York.

This common-carrier truck would have paid fees at the following rates in the four States in 1932:

Florida: Registration fees at $2 per 100 pounds gross weight, a gasoline tax of 7 cents per gallon, and a mileage tax of 2 cents per mile.

Michigan: Registration fees at $1.25 per 100 pounds net weight, a gasoline tax of 3 cents per gallon, and a public utility permit fee of $1 per 100 pounds net weight.

Kansas: Registration fees of $100, a gasoline tax of 3 cents per gallon, and a ton-mile tax of 0.5 mill per gross ton-mile, gross tonnage being twice the capacity plus net weight.

New York: Registration fees of 80 cents per 100 pounds ne weight (same rate for all classes), and a gasoline tax of 2 cents pe gallon until March 1 and 3 cents after that date. On the basis o the reported tax-earned gallonage, the average rate for the yea was 2.86 cents.

The rates in Florida would have resulted in the following payments for the truck specified:

Registration fees	$434
Gasoline tax	210
Mileage tax	300
Total	944

Total payments in the four States, computed in this manner are as follows:

Florida	$944.00
Michigan	353.25
Kansas	308.88
New York	179.40

DISPOSITION OF STATE MOTOR-VEHICLE FUNDS

In table 12 there is given an analysis of the purposes to which funds derived from State motor-vehicle fees and gasoline taxes were devoted in 1932. No data of this character were obtained in the survey; but the regular motor-vehicle and gasoline-tax tables published annually by the Bureau (table MV–2 and table G–1) give the disposition, according to State laws, of the funds reported each year by the States. Table 1 was made up by combining the data on disposition of funds given in these two tables for the year 1932. Various small differences exist between the data given in table MV–2, 1932, as published in 1933, and the data obtained in this survey. Only a part of the special fees paid by for-hire carriers were included in the earlier tabulation; and on the other hand, certain items such as dealers' licenses and fines and penalties were included in table MV–2 and omitted from the survey. The gasoline-tax table also includes certain miscellaneous receipts not carried in the survey totals. These differences tend to balance, with the result that the total given in table 12, $838,412,410, differs very little from the total of State fees and taxes, $838,830,978, obtained as a result of this survey.

A total of $20,383,242 was allotted from the motor-vehicle and gasoline-tax receipts for costs of collection and administration. This is not the total expended for these purposes, as a number of States make special appropriations for administration or pay collection costs out of other funds. The total also includes certain special items, such as reserves for refunds of gasoline tax, which enter largely as a matter of bookkeeping.

The sum of $457,700,193, or 54.59 percent of the total, was assigned to the State highway departments for construction and maintenance of State highways and bridges. In addition, $64,779,967 was devoted to the payment of interest and retirement charges on State highway bonds. The amount thus allotted to State highways was 62.32 percent of the total motor-vehicle and gasoline-tax receipts.

County and local road administrations were allotted $170,038,290, or 20.28 percent, and $25,286,375, or 3.0 percent, was assigned for interest and retirement of county road bonds.

The amount allocated for expenditure on city streets was $18,144,645, or 2.16 percent of the total.

Other items allocated to construction and maintenance of roads and bridges were $1,039,904, assigned in Massachusetts to the Metropolitan District Commission for the construction and maintenance of par boulevards, and $196,000, assigned to the New Jerse Free Bridge Commission. Two additional items ma

TABLE 12.—*Disposition of funds obtained from State taxation of motor vehicles in 1932* [1]

State	For collection and administration [2]	For construction and maintenance on rural roads		For highway bonds		For city streets	For State highway patrol	For other purposes related to roads and streets	For purposes not related to roads or streets				Total motor-vehicle fees and motor-fuel taxes [4]
		State highways	Local roads	State highway bond payments	County road bond payments				School	Unemployment relief	To general funds [3]	Other purposes	
Alabama	$149,150	$3,175,321	$3,570,714	$2,843,809									$10,039,291
Arizona	174,797	2,426,570	1,008,622										3,609,989
Arkansas	194,726	1,025,164	1,048,828	3,969,138	$1,723,113								7,960,999
California	1,664,862	27,015,372	14,990,429				$1,817,590					$31,967	45,520,220
Colorado	158,272	4,710,625	2,385,057			$162,219							7,116,203
Connecticut	1,032,587	11,653,875											12,686,462
Delaware		1,247,527		478,779	382,240								2,108,516
Florida	350,266	6,220,638	864		6,218,047				$4,937,001		$2,072,683		19,799,499
Georgia	4,200	11,590,657	1,989,102						1,989,101		191,277		15,764,337
Idaho	96,165	2,128,586	1,311,912	328,751								9,112	3,904,556
Illinois	182,098	24,002,038	12,023,984	8,362,613			1,150,000						15,720,733
Indiana	395,678	18,117,949	3,124,126			1,011,375	150,962						22,830,090
Iowa	619,859	14,548,787	3,498,780		1,600,000						[7] 373,399		20,640,825
Kansas	214,264	9,045,212	3,600,000										12,859,176
Kentucky	438,834	11,837,945	579,964										12,856,713
Louisiana	139,000	6,914,205		3,707,375					830,072			[8] 830,072	12,420,721
Maine	478,450	2,769,091	2,116,239	1,704,910			142,324						7,211,011
Maryland	357,639	8,414,384				2,103,595						[9] 75,000	10,950,618
Massachusetts	1,568,341	19,636,155		495,496			312,028	[10] $1,039,904				[11] 35,000	23,086,921
Michigan	1,067,592	23,392,187	11,335,287	4,082,059			389,914				3,615	[12] 25,668	10,296,322
Minnesota	315,210	12,996,555	3,333,519	423,950	2,996,223						56,797		20,122,254
Mississippi	219,262	2,978,798	4,229,487	339,053				[13] 215,103					7,981,703
Missouri	658,289	13,196,941		4,919,027									18,774,257
Montana	75,728	2,513,150	1,250,047	56,134								[14] 89,271	3,984,330
Nebraska	117,856	6,819,738	4,221,023										11,158,617
Nevada	30,541	977,177		114,839									1,122,557
New Hampshire	257,103	3,826,124		659,710									4,742,937
New Jersey	377,201	9,671,794	7,310,000	1,260,000		5,000,000	[15] 66,880	[16] 196,000		$8,116,021		[17] 90,000	32,087,899
New Mexico	99,071	1,324,258	281,363	1,170,168							105,511		2,980,371
New York	960,760	22,417,669	15,901,228							11,430,432	[18] 33,142,539		83,852,628
North Carolina	379,501	3,111,319	6,117,508	8,453,741	184,635		151,424	[19] 121,587			229,018		19,351,733
North Dakota	98,015	2,227,730	1,311,379										3,637,121
Ohio	685,532	23,872,054	21,683,703			6,152,862							52,694,151
Oklahoma	186,073	9,139,670	5,124,809								21,181		11,171,733
Oregon	391,894	5,866,699	1,473,581	1,128,172			279,000						12,139,346
Pennsylvania	2,636,670	46,188,157	5,056,398	6,041,150			690,955						60,616,630
Rhode Island	278,193	2,705,120	772,576	285,331									1,011,220
South Carolina	65,900	2,228,351	1,037,488	93,027	5,096,353		174,278						8,695,397
South Dakota	111,556	3,405,398	1,890,684										5,407,638
Tennessee	206,757	6,840,098	3,458,305	1,902,067	1,729,153		191,921				1,729,153		16,057,451
Texas	741,261	22,105,583	8,402,797		2,203,177				6,765,939				10,218,757
Utah	69,663	2,167,352		737,500									2,971,515
Vermont		3,808,061		285,000									4,093,061
Virginia	385,883	13,421,704	3,242,880										17,050,167
Washington	605,628	9,957,797	2,582,832				79,800						13,226,057
West Virginia	199,849	1,156,909		7,657,168									9,013,926
Wisconsin	822,206	11,141,318	8,088,269		2,853,404	597,360					1,727,166		25,229,723
Wyoming		1,462,081	354,506	278,000									2,094,587
Dist. of Columbia	120,560					[21] 2,787,204							2,907,761
Total	20,383,242	457,700,193	170,038,290	64,779,967	25,286,375	18,144,645	5,597,076	1,575,594	11,522,113	19,546,456	39,652,339	1,186,120	838,412,410
Percentage distribution	2.43	51.59	20.28	7.73	3.02	2.16	0.67	0.19	1.73	2.33	4.73	0.11	100.00

[1] This table was made up from the annual tables published by the Bureau, table MV 2, motor vehicle receipts, 1932, and table G 1, State gasoline taxes, 1932. Many of he notes accompanying these tables have been omitted, and the reader is referred to them for more detailed description of the items in this table.

[2] Many States pay collection cost from other State funds, for details see table MV 2 and table G 1. Administration cost includes balances allocated to reserve funds for dministrative purposes.

[3] To State general fund unless otherwise noted.

[4] The totals given in this column are the sum of the total gross receipts from motor-vehicle taxes, $321,273,510, as given in table MV 2, 1932, and the grand total earnings nder the gasoline-tax laws, $514,138,900, as given in table G-1, 1932. The latter sum includes $1,091,661 of receipts under gasoline-tax laws other than gasoline taxes paid by otor vehicles.

[5] Expenses of transportation of tax division of board of equalization.

[6] Aviation fund collected from aviation gasoline tax.

[7] To county general fund.

[8] To boards of commissioners of ports of New Orleans and Lake Charles Harbor.

[9] To conservation department for oyster propagation.

[10] To metropolitan district commission for construction and maintenance of park boulevards.

[11] For motor-vehicle liability insurance expenses.

[12] From aviation gasoline tax allocated to aeronautics fund.

[13] For sea walls protecting roads.

[14] For referendum expenses and experimental equipment.

[15] To State traffic commission.

[16] To free bridge commission.

[17] To department of commerce and navigation.

[18] Includes $1,486,937 to New York City general fund.

[19] For prison camp expenses for road work.

[20] To county general fund in lieu of personal property taxes on motor vehicles.

[21] Includes $105,996 for traffic signals.

e regarded as related to highway construction and maintenance. In Mississippi $215,103 was allotted for carrying charges on bonds issued for the construction of sea walls which serve, in part, at least, to protect highways. Of this amount, $117,817 was derived from a special gasoline tax levied for this purpose in three counties. In North Carolina $124,587 was used to defray the expenses of prison camps maintained in connection with convict labor on roads.

Traffic control claimed a share of the motor-vehicle taxes. Twelve States assigned funds to the support of the State highway patrols; in addition, New Jersey allotted $66,880 to the State traffic commission. The amount specifically assigned to traffic control, $5,597,076, was 0.67 percent of the total motor-vehicle fees and gasoline taxes.

A total of $74,907,028, or 8.93 percent, was devoted to purposes not related to roads and streets. Four

TABLE 13.—*Motor vehicles regisiered and tax-paid in the United States in 1932, tabulated for each State by type of vehicle and class of service*[1]

State	Passenger cars			Busses				Trucks and tractor trucks				Trailers and semitrailers				All vehicles	Motor-cycles	All vehicles, including motor-cycles
	Private cars [2]	Taxicabs and other for-hire cars	All passenger cars	School [3]	Contract, including sight-seeing	Public carrier [4]	All busses	Privately owned and operated [5]	Contract carrier	Common carrier	All trucks and tractor trucks	Privately owned and operated [5]	Contract carrier	Common carrier	All trailers and semi-trailers			
Alabama	193, 525	527	194, 052			219	219	31, 516		59	31, 575	4, 056			4, 056	229, 902	521	230, 423
Arizona	79, 835	141	79, 976	3	83	186	272	14, 151		536	14, 687	1, 803		53	1, 856	96, 791	309	97, 100
Arkansas	113, 157	250	113, 407			187	187	21, 832	[6] 1, 157		22, 989	2, 532	[6] 472		3, 004	139, 587	153	139, 740
California	1, 738, 385		1, 738, 385	790		1, 580	2, 370	232, 133		2, 044	234, 177	61, 853		900	62, 753	2, 037, 685	8, 338	2, 046, 023
Colorado	253, 752	367	254, 119			1, 735	1, 735	28, 182	392	1, 783	30, 357	325	56	203	584	286, 795	805	287, 600
Connecticut	268, 187	1, 167	269, 354			838	838	51, 388			51, 388	1, 290			1, 290	322, 870	1, 940	324, 810
Delaware	43, 311		43, 311	202		162	364	8, 666			8, 666	674			674	53, 015	233	53, 248
Florida	246, 281	1, 318	247, 599		55	412	467	36, 855	852	248	37, 955	7, 375	78	69	7, 522	293, 543	850	294, 393
Georgia	244, 392	560	244, 952	152	188	374	714	40, 977	86	987	42, 050	3, 750	13	258	4, 021	291, 737	977	292, 714
Idaho	81, 913		81, 913			96	96	12, 869	1, 006	155	14, 030	9, 905	128	22	10, 055	106, 094	306	106, 400
Illinois	1, 309, 701		1, 309, 701	31		1, 595	1, 626	177, 820			177, 820	8, 903			8, 903	1, 498, 050	5, 274	1, 503, 324
Indiana	674, 230		674, 230			877	877	122, 019			122, 019	23, 543			23, 543	820, 669	2, 529	823, 198
Iowa	605, 693		605, 693	2, 077		253	2, 330	67, 079	7, 333	470	74, 882	2, 608	241	25	2, 874	685, 779	1, 605	687, 384
Kansas	432, 724	81	432, 805		16	185	201	65, 489	5, 739	550	71, 778	1, 681	277	73	2, 031	506, 815	878	507, 693
Kentucky	258, 179	1, 118	259, 297			391	391	28, 710	2, 453	458	31, 621	(7)	(7)	(7)	(7)	291, 309	804	292, 113
Louisiana	195, 083	1, 517	196, 600			424	424	41, 757		96	41, 853	6, 447		46	6, 493	245, 370	660	246, 030
Maine	133, 837	1, 271	135, 108			113	113	36, 203			36, 203	4, 136			4, 136	175, 560	964	176, 524
Maryland	273, 463	6, 383	279, 846			733	733	41, 152		375	41, 527	1, 243		68	1, 311	323, 417	1, 553	324, 970
Massachusetts	694, 357		694, 357	643	1, 708	1, 650	4, 001	87, 777	15, 182		102, 959	691	426		1, 117	802, 434	1, 473	803, 907
Michigan	1, 001, 130	10, 796	1, 011, 926		485	540	1, 025	120, 760	1, 492	1, 021	123, 273	75, 799	801	938	77, 538	1, 213, 762	2, 998	1, 216, 760
Minnesota	581, 088		581, 088			215	215	92, 924	8, 448	278	101, 650	21, 023	416	90	21, 529	704, 482	1, 704	706, 186
Mississippi	126, 551		126, 551	1, 789	204	33	2, 026	25, 164			25, 164	2, 498			2, 498	156, 239	144	156, 383
Missouri	617, 995		617, 995			200	200	98, 151	74	1, 040	99, 265	9, 894	18	96	10, 008	727, 468	1, 545	729, 013
Montana	88, 611		88, 611			71	71	20, 144	297	80	20, 521	60			60	109, 263	198	109, 461
Nebraska	322, 335		322, 335			220	220	52, 294			52, 294	13, 478			13, 478	388, 327	834	389, 161
Nevada	24, 670	65	24, 735			116	116	6, 231	161	135	6, 527	601	12	5	618	31, 996	89	32, 085
New Hampshire	87, 531		87, 531	115		191	306	17, 378			17, 378	1, 286			1, 286	106, 501	905	107, 406
New Jersey	716, 491	4, 485	720, 976			5, 202	5, 202	128, 604			128, 604	3, 038			3, 038	857, 820	5, 257	863, 077
New Mexico	61, 546	167	61, 713			139	139	14, 826		194	15, 020	598		21	619	77, 491	226	77, 717
New York	1, 897, 754	31, 863	1, 929, 617			6, 127	6, 127	313, 765			313, 765	13, 788			13, 788	2, 263, 297	11, 593	2, 274, 890
North Carolina	324, 666	773	325, 439			625	625	47, 174	2, 387	701	50, 262	7, 339	522	404	8, 265	384, 591	1, 140	385, 731
North Dakota	129, 472	119	129, 591		20	31	51	22, 553	844	193	23, 590	3	36		39	153, 271	230	153, 501
Ohio	1, 420, 470		1, 420, 470			1, 360	1, 360	164, 436	[6] 3, 056		167, 492	45, 206	[6] 392		45, 598	1, 634, 920	5, 680	1, 640, 600
Oklahoma	370, 435		370, 435		38	287	325	43, 939	647	298	44, 884	(8)	(8)	(8)	(8)	415, 644	739	416, 383
Oregon	223, 407	173	223, 580	57	171	477	705	29, 281	4, 790	406	34, 477	1, 075	521	110	1, 706	260, 468	1, 422	261, 890
Pennsylvania	1, 440, 072	2, 855	1, 442, 927	2, 703	31	3, 423	6, 157	216, 334			216, 334	7, 555			7, 555	1, 672, 973	9, 805	1, 682, 778
Rhode Island	113, 581	873	114, 454			538	538	18, 416			18, 416	68			68	133, 476	824	134, 300
South Carolina	156, 515		156, 515		27	106	133	19, 389	286	47	19, 722	1, 715	167	28	1, 910	178, 280	483	178, 763
South Dakota	142, 468		142, 468		14	72	86	17, 272	172	2, 098	19, 542	8, 852			8, 852	170, 948	220	171, 168
Tennessee	265, 543	1, 250	266, 793			486	486	31, 434			31, 434	3, 294			3, 294	302, 007	1, 087	303, 094
Texas	1, 005, 186		1, 005, 186		72	723	795	188, 452	1, 890	1, 120	191, 462	36, 078	1	19	36, 098	1, 233, 541	3, 375	1, 236, 916
Utah	80, 920		80, 920		27	191	218	15, 758	192	146	16, 096	307	1	17	325	97, 559	382	97, 941
Vermont	69, 013	7	69, 020	2	2	142	146	8, 283		26	8, 309	479			479	77, 954	479	78, 433
Virginia	311, 578	1, 192	312, 770	940	20	438	1, 398	54, 923	7, 129	292	62, 344	1, 840	430	120	2, 390	378, 902	1, 882	380, 784
Washington	380, 070	729	380, 799	100	60	529	689	63, 425		401	63, 826	4, 210		86	4, 296	449, 610	1, 776	451, 386
West Virginia	190, 813	602	191, 415	116		690	806	28, 032	[6] 4, 884		32, 916	1, 661			1, 661	226, 798	999	227, 797
Wisconsin	587, 454		587, 454		5	447	452	107, 605		442	108, 047	1, 310		183	1, 493	697, 446	2, 204	699, 650
Wyoming	46, 150		46, 150	93		87	180	9, 682	7	190	9, 879	15		3	18	56, 227	116	56, 343
District of Columbia	135, 620	6, 573	142, 193		88	609	697	18, 286			18, 286	546			546	161, 722	689	162, 411
Total	20, 759, 140	77, 222	20, 836, 362	9, 813	3, 314	36, 325	49, 452	3, 141, 490	70, 956	16, 869	3, 229, 315	406, 431	5, 008	3, 837	415, 276	24, 530, 405	89, 197	24, 619, 602

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[1] Publicly owned and tax-exempt vehicles were excluded from this tabulation in all cases where segregation was possible. Nominal payments by such vehicles are included in table 13.

[2] Includes taxicabs and other for-hire cars in those States not reporting these vehicles separately, with the exception of California, which included taxicabs with light trucks. Also includes hearses and ambulances in 7 States which reported these vehicles separately.

[3] Publicly owned school busses, tax-exempt or paying only nominal fees, not included.

[4] Includes all busses reported in those States which did not separate these vehicles by class of service.

[5] Includes for-hire carriers in those States not reporting such vehicles separately.

[6] Includes common carriers.

[7] Full trailers not permitted by law; semitrailers included with trucks.

[8] No registration of trailers in 1932.

TABLE 14.—*State registration fees [1] imposed on motor vehicles of different types and classes of service in 1932*

State	Passenger cars			Busses				Trucks and tractor trucks				Trailers and semitrailers				All vehicles	Motorcycles	All vehicles, including motorcycles
	Private cars	Taxicabs and other for-hire cars	All passenger cars	School	Contract, including sight-seeing	Public carrier	All busses	Privately owned and operated	Contract carrier	Common carrier	All trucks and tractor trucks	Privately owned and operated	Contract carrier	Common carrier	All trailers and semitrailers			
Alabama	$2,404,936	$19,160	$2,424,096			$22,749	$22,749	$612,570		$1,940	$614,510	$36,068			$36,068	$3,097,423	$2,068	$3,099,491
Arizona	279,809	2,847	282,656	$60	$3,921	15,118	19,099	241,916		21,649	263,565	22,087		$2,258	24,345	589,665	1,082	590,747
Arkansas	2,099,623	7,910	2,107,533			15,439	15,439	533,459	$65,377		598,836	31,050	$18,705		49,755	2,771,563	1,730	2,773,293
California	5,249,998		5,249,998	26,884		[2] 690	27,574	2,552,641		[2] 4,308	2,556,949	340,640		[2] 463	341,103	8,175,624	26,033	8,201,657
Colorado	1,252,463	1,883	1,254,346			58,242	58,242	342,956	7,145	34,833	384,934	5,000	1,400	6,190	12,590	1,710,112	1,610	1,711,722
Connecticut	4,515,788	53,628	4,569,416			147,957	147,957	1,484,631			1,484,631	37,774			37,774	6,239,778	8,538	6,248,316
Delaware	622,079		622,079	6,328		11,220	17,548	222,950			222,950	9,168			9,168	871,745	1,085	872,830
Florida	4,003,153	58,812	4,061,965		11,342	105,226	116,568	1,000,291	70,883	29,355	1,100,529	33,717	7,278	6,267	47,262	5,326,324	6,415	5,332,739
Georgia	2,995,342	9,310	3,004,652	4,709	6,553	10,896	22,158	700,509	2,399	27,595	730,503	33,999	104	2,353	36,456	3,793,769	4,853	3,798,622
Idaho	1,192,461		1,192,461			24,166	24,166	307,399	43,191	18,867	369,457	10,698	1,496	1,714	13,908	1,599,992	1,530	1,601,522
Illinois	12,212,194		12,212,194	128		130,263	130,391	3,840,364			3,840,364	116,496			116,496	16,299,445	16,440	16,315,885
Indiana	4,164,349		4,164,349			68,648	68,648	1,455,292			1,455,292	128,288			128,288	5,816,577	4,640	5,821,217
Iowa	9,130,146		9,130,146	31,155		25,489	56,644	1,374,318	387,435	37,265	1,799,018	24,642	9,695	950	35,287	11,021,095	5,710	11,026,805
Kansas	4,354,320	2,386	4,356,706		1,893	4,502	6,395	831,315	105,201	15,134	951,650	10,294	3,035	865	14,194	5,328,945	4,122	5,333,067
Kentucky	2,953,843	19,184	2,973,027			52,508	52,508	1,005,498	116,223	28,239	1,149,960					4,175,495	3,323	4,178,818
Louisiana	2,928,750	29,939	2,958,689			42,988	42,988	887,910		3,648	891,558	133,460		3,538	136,998	4,030,233	4,111	4,034,344
Maine	1,686,694	42,369	1,729,063			10,920	10,920	661,711			661,711	9,896			9,896	2,411,590	5,150	2,416,740
Maryland	2,078,199	46,975	2,125,174			(3)		391,351		(3)	391,351	35,741		(3)	35,741	2,552,266	7,587	2,559,853
Massachusetts	2,489,699		2,489,699	1,285	20,751	67,350	89,386	963,414	253,103		1,216,517	34,412	17,084		51,496	3,847,098	1,974	3,849,072
Michigan	14,105,480	212,873	14,318,353		73,628	65,659	139,287	3,538,816	108,777	70,378	3,717,971	366,764	52,851	63,237	477,046	18,652,657	11,340	18,663,997
Minnesota	7,922,212		7,922,212			111,281	111,281	1,660,532	207,141	43,027	1,910,700	53,588	6,553	2,371	68,318	10,012,511	5,844	10,018,355
Mississippi	1,587,443		1,587,443	20,580	14,831	4,225	39,636	442,105			442,105	46,129			46,129	2,115,313	1,483	2,116,796
Missouri	8,036,791		8,036,791			2,632	2,632	1,009,261	1,130	14,100	1,024,491	30,465	529	1,680	32,674	9,096,588	7,298	9,103,886
Montana	985,855		985,855			798	798	227,073	(4)	2,596	229,669	276			276	1,216,598	768	1,217,366
Nebraska	2,756,438		2,756,438			19,390	19,390	491,459			491,459	12,658			12,658	3,279,945	2,569	3,282,514
Nevada	220,474	785	221,259			4,420	4,420	87,318	5,605	4,999	97,922	2,832	581	225	3,638	327,239	392	327,631
New Hampshire	1,146,623		1,146,623	4,915		16,625	21,540	539,500			539,500	15,408			15,408	1,723,071	4,786	1,727,857
New Jersey	7,203,474	71,345	7,274,819			298,512	298,512	3,875,212			3,875,212	118,255			118,255	11,566,798	10,514	11,577,312
New Mexico	531,433	9,452	540,885			13,868	13,868	244,424		4,694	249,118	6,191		469	6,660	810,531	689	811,220
New York	25,784,935	519,160	26,304,095			308,621	308,621	9,953,274			9,953,274	201,113			201,113	36,767,103	16,703	36,813,806
North Carolina	4,838,630	42,231	4,880,861			43,672	43,672	955,131	151,928	29,466	1,136,525	130,533	49,846	21,870	202,249	6,263,307	4,409	6,267,716
North Dakota	1,385,315	1,874	1,387,189		628	2,167	2,795	344,237	41,605	10,660	396,502	15	499		514	1,787,000	1,428	1,788,428
Ohio	11,763,706		11,763,706			288,435	288,435	5,329,706	275,960		5,605,666	383,986	32,866		416,852	18,074,659	23,413	18,098,072
Oklahoma	3,685,703		3,685,703		605	7,685	8,290	963,341	(4)	8,148	971,489					4,665,482	6,015	4,671,497
Oregon	4,789,094	1,742	4,793,836	3,582	6,715	59,145	69,442	813,626	234,875	33,936	1,082,437	13,353	10,854	7,507	31,714	5,977,429	5,606	5,983,035
Pennsylvania	14,821,328	72,482	14,893,810	93,294	4,299	496,402	593,995	7,001,320			7,001,320	127,676			127,676	22,616,801	26,748	22,643,549
Rhode Island	1,250,910	29,101	1,280,011			49,997	49,997	437,173			437,173	1,721			1,721	1,768,902	3,038	1,771,940
South Carolina	1,810,814		1,810,814		616	(3)	616	405,766	10,158	(3)	415,924	41,288	7,758	(3)	49,046	2,276,400	1,964	2,278,364
South Dakota	1,932,170		1,932,170		1,007	5,999	7,006	464,816	(4)	(4)	464,816	13,415			13,415	2,417,407	742	2,418,149
Tennessee	3,047,984	20,511	3,068,495			28,185	28,185	828,023			828,023	47,730			47,730	3,972,433	4,331	3,976,764
Texas	8,488,045		8,488,045		2,944	85,841	88,785	3,791,451	62,797	40,788	3,895,036	313,005	29	454	313,488	12,785,354	14,685	12,800,039
Utah	558,969		558,969		433	3,280	3,713	192,503	5,055	7,062	204,620	3,870	25	600	4,495	771,797	936	772,733
Vermont	1,480,761	176	1,480,937	144	173	17,283	17,600	419,756		1,750	421,506	2,792			2,792	1,922,835	3,016	1,925,851
Virginia	4,839,253	37,935	4,877,188	4,700	2,800	38,909	46,409	889,244	126,090	12,441	1,027,775	15,812	7,689	9,974	33,475	5,984,847	7,748	5,992,595
Washington	1,115,380	12,224	1,127,604	3,763	2,822	37,245	43,830	817,078		13,685	830,763	47,548		5,727	53,275	2,055,472	4,738	2,060,210
West Virginia	2,732,623	35,281	2,767,904	8,600		(3)	8,600	599,205	257,942		857,147	6,566			6,566	3,640,217	4,546	3,644,763
Wisconsin	7,305,776		7,305,776		1,346	219,961	221,307	2,176,020		24,470	2,200,490	77,387		12,955	90,342	9,818,915	11,940	9,830,855
Wyoming	476,215		476,215	1,505		2,452	3,958	180,671	187	5,992	186,850	359		90	449	667,472	510	667,982
District of Columbia	135,650	6,573	142,223		88	609	697	25,000			25,000	546			546	168,466	689	169,155
Total	213,357,330	1,368,148	214,725,478	211,633	157,395	3,047,669	3,416,697	68,113,536	2,540,207	551,025	71,204,768	3,134,711	228,877	151,757	3,515,345	292,862,288	326,889	293,189,177

[1] Payments tabulated correspond to numbers of vehicles listed in table 13, except where noted.

[2] Public-carrier busses and common carriers of property in California were not required to pay registration fees, a receipts tax being imposed in lieu thereof. The figures given are estimated payments by 30 public-carrier busses, 278 common-carrier trucks, and 15 common-carrier trailers and semitrailers, which were adjudged common or public carriers for a part of their operations.

[3] Public-carrier busses and common carriers of property in these States were not required to pay registration fees, but paid passenger-mile and ton-mile taxes, respectively, in lieu thereof

[4] Payments not segregated from those of private carriers.

TABLE 15.—*Special State fees and taxes imposed on motor vehicles (chiefly for-hire carriers) in 1932; tabulated for each State by type o vehicle and class of service*

State	Taxicabs and other cars for hire		Busses					Contract carriers of property		
			Contract, including sight-seeing		Public-carrier			Trucks and tractor trucks		
	Receipts taxes	Other special fees [1]	Mileage, ton-mile or passenger-mile taxes	Other special fees [1]	Mileage, ton-mile or passenger-mile taxes	Receipts taxes	Other special fees [1]	Mileage or ton-mile taxes	Receipts taxes	Other special fees [1]
Alabama					$20,620		$350			
Arizona	$2,791					$13,835				
Arkansas						8,795			$26,669	
California						411,072				
Colorado					28,349			$16,981		$25
Connecticut						180,867				
Florida			$2,489		54,466			18,166		
Georgia		[2] $4,988			52,706		13,175	3,666		2,38
Idaho						4,399				
Iowa					188,873					38,06
Kentucky					54,067		2,690	50,960		39,76
Maryland					175,694					
Michigan							64,736			71,35
Minnesota							425			
Mississippi					2,858					
Missouri							36,715			
Montana							710			2,97
Nevada		2,170					17,910			23,22
New Jersey					[3] 79,802					
New Mexico					32,393		(4)			
North Carolina						30,658				
North Dakota		815		$302			652			
Ohio							92,019			[5] 171,84
Oklahoma			337	38	66,661		500	67,330		5,58
Oregon		96		4,324	86,453					180,88
South Carolina					28,896					
South Dakota						4,200	500			4,82
Tennessee [6]		12,063			72,288		18,773			
Texas							21,271			[4] 14,97
Utah			6,232		47,968			6,013		
Virginia						50,897				
Washington						34,166				
West Virginia					149,662					
Wisconsin					53,884		22,265	(7)		(7)
Wyoming					10,365		1,905	297		15
District of Columbia		95,074		3,650	47,726					
Total	2,791	115,206	9,058	8,314	1,253,731	738,889	294,596	163,413	26,669	556,2

[1] Includes franchise or special license fees, privilege taxes, permit fees, fees for certificates of convenience and necessity, etc.
[2] Occupation tax paid by "U-Drive-It" car companies.
[3] Mileage tax on interstate busses only.
[4] Payments of certificate fees included with undistributed fees.
[5] See column headed "Undistributed fees, etc" for payments by out-of-State property carriers.
[6] Payments of mileage tax, privilege tax, and inspection fees by property carriers given in column headed "Undistributed fees, etc."
[7] See column headed "Undistributed fees, etc."

States—Florida, Georgia, Louisiana, and Texas—allotted motor-vehicle or gasoline-tax funds to the support of schools, the total amount being $14,522,113. New Jersey and New York devoted funds aggregating $19,546,456 to unemployment relief. A total of $39,652,339 in 11 States was paid into general funds, chiefly those of the States. In Louisiana $830,072 was allocated to the boards of commissioners of the ports of New Orleans and Lake Charles Harbor, for use in payment of principal and interest on bonds and other payments in connection with the establishment of port facilities. The remaining items were small in amount, and were either of an administrative character or were offsets against the taxation of gasoline used for other than motor-vehicle purposes.

DIVERSION OF FUNDS GREATER IN 1933

The tendency toward the use of motor-vehicle and gasoline-tax receipts for purposes not related to highways was more strongly in evidence in 1933 than in 1932. A total of $17,568,505 was allocated to the support of schools; $29,997,563 was devoted to the relief of unemployment or other emergency relief; and $32,971,664 was paid into State, county, and municipal general funds. Nearly $10,000,000 was expended in the financing of debt obligations not related to highways, including $1,100,000 transferred to the real estate bond payment fund in North Dakota, $2,262,625 devoted to retirement of State warrants in Oklahoma $4,042,235 paid on State debt obligations in Pennsylvania, $1,404,569 in payments on rural credit bonds in South Dakota, and $869,057 in payments on Stat emergency relief bonds in Washington. The sum o $950,695 was devoted to harbor improvements an other purposes related to navigation.

The total of the items listed above is $91,166,913 which is 11.1 percent of the total receipts in 1933 fro State motor-vehicle fees and gasoline taxes, $822,097,515. In addition to these specific diversions there wer miscellaneous items aggregating $3,065,002, a numbe of which were largely administrative in character. I these are added the total funds devoted to purposes no related to roads and streets in 1933 are found to hav been $94,231,915.

REGISTRATIONS AND RECEIPTS BY STATES TABULATED

The greater part of the foregoing discussion of Stat taxation of motor vehicles in 1932 was based on figure for the country as a whole, as it was impossible in th space available to give complete figures for individua States. In tables 13, 14, 15, and 16 registrations an payments of fees are given for each State. Table 1 lists all vehicles registered and tax-paid, by type o

TABLE 15.—*Special State fees and taxes imposed on motor vehicles (chiefly for-hire carriers) in 1932, tabulated for each State by type of vehicle and class of service*—Continued

State	Contract carriers of property—Continued			Common carriers of property							
	Trailers and semitrailers			Trucks and tractor trucks			Trailers and semitrailers			Undistributed fees, etc.	All special fees and taxes
	Mileage or ton-mile taxes	Receipts taxes	Other special fees [1]	Mileage or ton-mile taxes	Receipts taxes	Other special fees [1]	Mileage or ton-mile taxes	Receipts taxes	Other special fees [1]		
Alabama				$3,109		$706					$24,785
Arizona					$13,340			$2,541			32,510
Arkansas		$20,743									56,207
California					165,229			164,664			740,965
Colorado	$2,311		$36	34,931		2,168	$7,708		$217		92,985
Connecticut											180,867
Florida	1,605			14,932			8,480				130,138
Georgia	456		360	52,744		27,329	16,557		7,144	[8] $7,527	189,033
Idaho					4,179			840			9,418
Iowa			1,585	91,265						20	319,803
Kansas										[10] 186,153	186,153
Kentucky				27,577		5,150					180,204
Maryland				67,758							213,452
Michigan			36,731			57,934			51,797		282,555
Minnesota						661			214		1,300
Mississippi										[14] 1,886	4,744
Missouri						50,321			11,052		98,088
Montana						800					4,480
Nevada			3,155			13,545			860		60,863
New Jersey											79,802
New Mexico				10,130		(12)	145		(12)	[12] 2,927	45,595
North Carolina					30,083			22,329			83,070
North Dakota						4,135					5,904
Ohio			7,950							[11] 28,316	300,129
Oklahoma				32,825		16,405					189,677
Oregon			7,453	99,785			15,416				394,115
Pennsylvania										[13] 33,946	33,946
South Carolina				6,283			2,863				38,042
South Dakota					23,471	13,500					46,491
Tennessee										[15] 31,951	135,075
Texas			[9] 14			[13] 11,234			[16] 209	22,898	70,598
Utah	46			3,594			610				64,463
Virginia					4,692			5,333			60,922
Washington					46,364			17,307			97,837
West Virginia											149,662
Wisconsin				33,774		29,226	33,897		2,044	[17] 248,588	423,678
Wyoming				9,296		4,161	243		66		26,486
District of Columbia											146,450
Total	4,418	20,743	57,284	518,003	287,358	237,275	85,919	213,017	73,633	564,212	5,230,792

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[1] Includes franchise or special license fees, privilege taxes, permit fees, fees for certificates of convenience and necessity, etc.
[8] Occupation tax on trucks operated by gas and oil companies.
[9] Franchise fees imposed on 4 motorcycles operating as contract carriers.
[10] Total payments of ton-mile tax by carriers of persons and property; not allocated by class of service.
[11] Payments of mileage taxes by trucks not classified by class of service.
[12] Payments of certificate fees not broken down as between passenger and property carriers. Contract carriers, $1,756; common carriers, $1,171.
[13] Payments of franchise fees and corporation taxes by out-of-State carriers of property.
[14] Payments of receipts taxes by for-hire carriers of persons and property, not allocated by class of service.
[15] Includes payments by property carriers, mileage tax, $23,669, privilege tax, $6,587, inspection fees, $1,695.
[16] Payments of certificate fees not allocated by type of vehicle: contract carriers, $17,270, common carriers, $5,628.
[17] Includes $213,533 in ton-mile taxes and $33,355 in permit fees paid by contract and other commercial property carriers which were not segregated from private carriers; also $1,700 in certificate fees paid by common carriers of property.

vehicle and class of service. The break-down by rated capacity is not given. Table 14 gives the corresponding payments of registration fees and table 15 the special fees paid by commercial carriers. In table 16 are given the miscellaneous fees paid by motor-vehicle owners, including operators' and chauffeurs' license fees, fees for certificates of title, transfer of registration fees, and miscellaneous small items.

OTHER TAXATION IMPOSED ON MOTOR VEHICLES IN 1932

COUNTY TAXES FOUND IN ONLY FIVE STATES

Aside from the levying of personal property taxes, the county unit of government has entered the field of motor-vehicle taxation to but a very limited extent. Special county fees and taxes were found to exist in only five States in 1932, and the collections reported were only $1,703,455. The actual total collected by counties may have been somewhat greater, since replies were not received from all the counties to which questionnaires were sent; but it is believed that such charges exist only in the five States named. The data on county fees and taxes are given in table 17.

The most significant fact revealed by this table is that four of the States in which counties levy special taxes on motor vehicles—Alabama, Louisiana, Mississippi, and Tennessee—are in the South and are contiguous. The remaining State, Nevada, yielded only $3,781 in county motor-vehicle fees.

By far the largest single item was reported in Louisiana, where the parishes collected more than $1,000,000 in gasoline taxes. Counties in Alabama and Mississippi also levied gasoline taxes, those in the latter State being used in financing the construction of sea walls. Registration fees or wheel taxes in two Tennessee counties yielded $133,641. The remaining items, in Louisiana, Mississippi, and Nevada, were small.

MUNICIPAL TAXES MORE FREQUENTLY IMPOSED

Municipal fees and taxes (other than personal-property taxes) imposed on motor vehicles were found in 39 States in 1932. The total collections reported were $14,157,822.

TABLE 16.—*Miscellaneous State fees imposed on motor-vehicle owners in 1932*

State	Operators' licenses				Certificates of title			Miscellaneous fees						Grand total
	Private	Chauffeur	Duplicates	Total	Issues and transfers	Duplicates	Total	Transfers or reregistrations	Duplicate registrations	Duplicate car plates	Temporary entry permits	Fees for official cars	Other fees	
Alabama		$12,790		$12,790										$12,790
Arizona	$4,158	9,356		13,514	$43,278	$1,215	$44,493	$13,464		$581			$6,004	78,056
Arkansas		17,376		17,376				2,239						19,615
California		131,860	$32,881	164,741				801,823	$49,512	13,541	$4,930		110,183	1,144,730
Colorado	168,859	15,188		184,047	94,611		94,611	20,642		1,768	7,408		1,338	309,814
Connecticut	1,221,678	18,725	6,931	1,247,334				61,042	2,384		35,738		64,844	1,411,342
Delaware	103,509			103,509	19,606		19,606							123,115
Florida		2,921		2,921	99,907	4,870	104,777	8,816	52	3,482		$41,008		161,056
Georgia		7,544		7,544				4,901	366				1,555	14,366
Idaho		754		754		2,663	2,663			316	7,091			10,824
Illinois		230,073		230,073				181,339		60,808		13,764	72,987	558,971
Indiana	16,753	12,988		29,741	132,244		132,244	150,962		28,705				341,652
Iowa	112,350	45,054	3,700	161,104	111,580		111,580	38,521	4,023	1,623				316,851
Kansas	10,090	11,642	1,250	22,982				50,402	9,204	1,644			220	84,452
Kentucky		26,905		26,905				69,662			241		1,614	98,422
Louisiana		59,250	146	59,396							409			59,805
Maine	380,996	84,687	1,008	466,691						462	120			467,273
Maryland	97,634	141,267		238,901	117,869		117,869	64,167	8,013					428,950
Massachusetts	2,174,712			2,174,712					37,004	7,146			5,527	2,224,389
Michigan	394,716	116,891	7,373	518,983	379,014	14,926	393,940	168,486		30,680	1,030			1,113,119
Minnesota		49,383	262	49,645					445	5,218	981	1,729		58,018
Mississippi										5,908	8,669	2,078		16,655
Missouri	19,191	107,178		126,369	267,029		267,029							393,398
Montana		670		670	24,996	357	25,353		1,551	46	416		13,773	41,809
Nebraska	4,967			4,967				28,152	10,898	1,667				45,684
Nevada					2,669	103	2,772		49			277		3,098
New Hampshire	180,283	102,463		282,746						13,399	604		2,263	299,012
New Jersey	3,251,282			3,251,282				298,436	20,525	6,878			35,840	3,612,961
New Mexico														
New York	1,322,046	1,646,352		2,968,398				816,671			143,971		293,093	4,222,133
North Carolina					69,487		69,487					9,460		78,947
North Dakota					27,704	1,134	28,838			220		463		29,521
Ohio		66,375		66,375				125,795	4,106	9,849				206,125
Oklahoma					148,274	4,974	153,248					2,101		155,349
Oregon	16,850	12,734	2,900	32,484	97,521	1,910	99,431		780	1,614	304		112	134,725
Pennsylvania	4,400,208		12,648	4,412,856	1,535,858	8,901	1,544,759	176,718	11,691	12,476			4,325	6,162,825
Rhode Island	341,417	1,512	2,710	345,639				46,176	1,492			2,078	1,245	396,630
South Carolina	103,477	1,020		104,497	8,832		8,832					684		114,013
South Dakota					16,004	2,534	18,538					242		18,780
Tennessee					586,851		586,851	35,028				1,581		623,460
Texas		230,352	2,395	232,747				106,440	1,033	17,918	400		24,950	383,488
Utah		4,081		4,081	16,044		16,044							20,125
Vermont	233,959			233,959				26,596			260	3,995		264,810
Virginia		57,903	50	57,953	161,051	16,207	177,258	57,391	5,691		13			298,306
Washington	61,744		800	62,514				960				6,192		69,696
West Virginia	34,718	68,627		103,345	89,474		89,474	25,065	1,233	6,951			900	226,968
Wisconsin	8,523		6,442	14,965	128,323		128,323					6,132		149,420
Wyoming					12,829		12,829							12,829
Dist. of Columbia	221,133	16,974	3,155	241,262	87,227	2,163	89,390	12,994	1,175	572				345,393
Total	14,885,253	3,310,898	84,651	18,280,802	4,278,282	61,957	4,340,239	3,392,888	171,227	233,472	212,585	91,784	640,773	27,363,770

TABLE 17.—*County fees and taxes on motor vehicles in 1932, other than personal property taxes*

State	Total fees and taxes	Registration or wheel taxes		Gasoline taxes		Franchise fees		Other fees and taxes	
		Number reporting	Amount	Number reporting	Amount	Number reporting	Amount	Number reporting	Amount
Alabama	$273,255			6	$273,255				
Louisiana	1,141,035			45	1,138,729	26	[1] $2,306		
Mississippi	151,740			3	[2] 117,817			2	[3] $33,923
Nevada	3,781					3	[4] 3,781		
Tennessee	133,644	2	$133,644						
Total	1,703,455	2	133,644	54	1,529,801	29	6,087	2	33,923

[1] Occupational license fees on taxicabs, jitneys, busses, drays, transfers, etc.
[2] Special gasoline tax for road-protecting sea walls.
[3] Road and bridge privilege tax.
[4] On interstate bus and truck operations.

While the total sum reported can hardly include every dollar actually collected from motor-vehicle owners by municipalities, it is believed to be a fairly close approximation of the truth. Questionnaires were mailed to 9,128 municipalities, and follow-up queries were sent to those which failed to answer the first communication. The total number of municipalities submitting replies was 6,598, or 72 percent. Only 1,537, however, reported collections, the remainder, or 5,061, definitely stating that they collected no special fees or taxes from motor-vehicle owners. The assumption might be made that the great majority of the municipalities not answering the questionnaire also had no fees of this character.

In table 18 there is given a detailed analysis of the questionnaire survey, showing for each State the number of municipalities queried, the number replying and the amounts of the fees reported.

The most prevalent type of fee, although not the most productive, was that of franchise taxes, frequently levied on taxicabs, busses, and for-hire trucks, and sometimes upon occupations in which motor vehicles are used, such as drayage and the like. Fees of this nature were reported in 34 States, and the total collected was $2,053,086.

Municipal gasoline taxes were found in only six States, in widely separated regions of the South and West, but the total collected was $2,602,083, of which Missouri alone accounted for 67 percent.

Registration fees imposed by municipalities amounted to $9,100,795. Of this total the State of Illinois alone accounted for 68 percent. Other fees included such items as operators' and chauffeurs' licenses.

Among the 39 States in the table of municipal fees, the States of Illinois and Missouri far exceeded any others, and together represented about 65 percent of the national total.

TABLE 18.—*Municipal fees and taxes on motor vehicles in 1932 other than personal property taxes*

State	Total number of municipalities queried	Total number of municipalities replying	Number of municipalities reporting fees	Number of municipalities reporting no fees	Total fees reported	Registration fees		Gasoline taxes		Franchise fees		Other fees	
						Number reporting	Amount	Number reporting	Amount	Number reporting	Amount	Number reporting	Amount
Alabama	296	207	115	92	$830,341	41	$82,632	88	$735,575	15	$8,779	6	$3,355
Arizona	34	1	1		180					1	180		
Arkansas	388	205	61	144	212,481	56	205,908			8	5,022	4	1,554
California	277	167	58	109	212,365					58	210,411	1	1,954
Colorado	246	232	28	204	28,821					26	28,061	4	760
Connecticut	[1] None												
Delaware	[1] None												
Florida	13	13	12	1	85,427			12	85,427				
Georgia	577	235	15	220	18,484	7	7,264			9	10,482	3	738
Idaho	[1] None												
Illinois	440	372	205	167	6,263,956	191	6,207,095			53	37,538	18	19,323
Indiana	284	263	36	227	105,382					36	105,382		
Iowa	186	160	28	132	7,239					28	6,508	5	731
Kansas	[1] None												
Kentucky	261	214	107	107	305,836	79	298,681			61	7,155		
Louisiana	1	1	1		234,000							1	234,000
Maine	[1] None												
Maryland	[1] None												
Massachusetts	[1] None												
Michigan	484	420	46	374	159,516					40	152,710	22	6,806
Minnesota	103	98	18	80	18,958					18	18,958		
Mississippi	306	126	15	111	446					15	446		
Missouri	769	359	148	211	2,971,873	126	1,150,280	36	1,743,644	35	77,949		
Montana	128	92	18	74	10,023					14	1,776	10	8,217
Nebraska	17	17	10	7	103,131	1	102,058			9	1,073		
Nevada	16	1	1		2,166			1	2,166				
New Hampshire	87	84	8	76	1,095					8	1,095		
New Jersey	572	566	115	451	883,185					114	882,188	6	997
New Mexico	57	49	10	39	37,082			5	29,398	5	1,065	5	6,619
New York	119	128	72	56	235,262					72	234,428	1	834
North Carolina	378	315	93	222	155,122	88	81,869					24	73,253
North Dakota	7	7	7		2,405					1	1,580	6	825
Ohio	56	42	34	8	62,337					34	44,591	7	17,746
Oklahoma	[1] None												
Oregon	190	160	29	131	20,804					29	20,804		
Pennsylvania	993	685	9	676	70,111					9	68,405	2	1,706
Rhode Island	7	1	1		4,905					1	4,380	1	525
South Carolina	42	36	6	30	20,034	6	7,542					1	12,492
South Dakota	13	11	11		1,303					11	1,303		
Tennessee	27	27	23	4	307,028	22	255,765			2	43,262	2	8,001
Texas	568	336	22	311	21,533					22	21,533		
Utah	2	2	2		15,153					2	13,761	2	1,392
Vermont	302	264	7	257	768					7	768		
Virginia	199	173	99	74	714,262	95	701,701			17	12,561		
Washington	66	54	27	27	16,682					27	16,682		
West Virginia	[1] None												
Wisconsin	502	399	34	365	11,518					34	11,518		
Wyoming	85	76	5	71	6,605			1	5,873	1	732		
Total	9,128	6,598	1,537	5,061	14,157,822	712	9,100,795	143	2,602,083	828	2,053,086	131	401,858

[1] Official statement from State sources indicated that no municipal fees or taxes were levied in 1932.

PERSONAL-PROPERTY TAXES CHARGED AGAINST MOTOR VEHICLES

Since personal property taxes upon motor vehicles are entirely distinct from the other types of fees and taxes paid by motor-vehicle owners, a special inquiry on this subject was undertaken in the several States simultaneously with the general statistical investigation. The statisticians in each State and field representatives of the Bureau cooperated in examining official reports, interviewing officials, and collecting basic information by means of questionnaires to local governmental authorities. In general, the response given to these questionnaires was excellent. With the resulting mass of information, extended by approximations based on the fact that taxes tend to be much the same in communities of the same type in the same general location, it was possible in practically all States to estimate with fair accuracy not only the total personal property taxes chargeable against motor vehicles, but also the division of the imposts among the governmental units levying them.

The information it was desired to obtain was the total personal-property tax levied by all governmental units in the year 1932. The data assembled did not all refer to that specific year. Because of a difference in the fiscal years of governmental units, and also because the assessment, levy, and collection of a tax involve a considerable length of time, it is impossible to get uniform information. The assessed value may be fixed in 1 year and the tax collected in another. The same may be, and often is, true of the levy and collection of the tax. Even after the payment is due, another considerable period elapses before the tax becomes delinquent. Thus, it was only natural that, when information was collected from thousands of governmental subdivisions, there should be some confusion as to the item to be reported as the motor-vehicle property tax for 1932.

Comprehensive and adequate data were obtained from all States. While in most cases the complete figures could not be obtained, sufficient facts were supplied to make possible accurate estimates. For a number of States the figures are known to be entirely correct, as they were based on complete records.

The essential results of the research and analysis are set forth in tables 19, 20, and 21. The first of these tables is a summary of the principal facts brought out by the analysis. Table 20 gives a comparison among the various States of the personal property taxes levied and collected in 1932. Table 21 gives a break-down of the taxes collected, according to the tax-levying jurisdictions.

TABLE 19.—*Summary of personal-property taxes levied and collected against motor vehicles in 1932*

Method of taxation	Number of States	Number of vehicles licensed (1931)	Personal-property taxes		
			Levied	Per vehicle	Collected
Exempt	17	11,854,346	None	None	None
Special laws	6	1,700,930	$9,921,000	$5.83	$9,921,000
General laws	26	12,258,827	34,160,000	2.79	25,959,000
Total	49	25,814,103	44,081,000	3.16	35,880,000

TABLE 20.—*Personal-property taxes levied and collected against motor vehicles in 1932; totals and percentages tabulated by States*

State	Taxes levied	Taxes collected	Percentage of total collected
Alabama	$818,000	$670,000	81.9
Arizona	797,000	730,000	91.5
Arkansas	259,000	192,000	74.2
California	8,534,000	5,285,000	61.9
Colorado	1,143,000	853,000	74.6
Connecticut	2,039,000	1,790,000	87.8
Delaware	None	None	None
District of Columbia	175,000	175,000	100.0
Florida	None	None	None
Georgia	694,000	542,000	78.1
Idaho	None	None	None
Illinois	2,190,000	1,855,000	84.7
Indiana	2,256,000	2,017,000	89.4
Iowa	None	None	None
Kansas	1,032,000	908,000	88.0
Kentucky	999,000	850,000	85.1
Louisiana	1,077,000	785,000	72.8
Maine	1,034,000	1,034,000	100.0
Maryland	1,487,000	1,487,000	100.0
Massachusetts	6,184,000	6,184,000	100.0
Michigan	None	None	None
Minnesota	None	None	None
Mississippi	559,000	447,000	80.0
Missouri	1,991,000	1,593,000	81.5
Montana	323,000	283,000	87.8
Nebraska	932,000	689,000	73.9
Nevada	135,000	133,000	98.1
New Hampshire	513,000	513,000	100.0
New Jersey	None	None	None
New Mexico	None	None	None
New York	None	None	None
North Carolina	840,000	639,000	76.0
North Dakota	None	None	None
Ohio	None	None	None
Oklahoma	None	None	None
Oregon	None	None	None
Pennsylvania	None	None	None
Rhode Island	977,000	853,000	87.4
South Carolina	449,000	362,000	80.6
South Dakota	None	None	None
Tennessee	133,000	133,000	100.0
Texas	2,186,000	1,715,000	69.0
Utah	357,000	268,000	75.0
Vermont	None	None	None
Virginia	699,000	516,000	73.7
Washington	1,897,000	1,393,000	65.0
West Virginia	544,000	458,000	84.3
Wisconsin	None	None	None
Wyoming	228,000	228,000	100.0
Total	44,081,000	35,880,000	81.4

TABLE 21. *Personal-property taxes collected on motor vehicles in 1932, grouped according to tax-levying jurisdictions*

State	Tax-levying jurisdictions			
	State	County	Other	Total
Alabama	$163,000	$379,000	$128,000	$670,000
Arizona	208,000	385,000	137,000	730,000
Arkansas	44,000	38,000	110,000	192,000
California	None	3,873,000	1,412,000	5,285,000
Colorado	94,000	154,000	605,000	853,000
Connecticut	43,000	23,000	1,724,000	1,790,000
Delaware	None	None	None	None
District of Columbia [1]	None	None	475,000	475,000
Florida	None	None	None	None
Georgia	91,000	252,000	199,000	542,000
Idaho	None	None	None	None
Illinois	185,000	198,000	1,472,000	1,855,000
Indiana	205,000	340,000	1,472,000	2,017,000
Iowa	None	None	None	None
Kansas	78,000	199,000	631,000	908,000
Kentucky	149,000	199,000	502,000	850,000
Louisiana	148,000	233,000	404,000	785,000
Maine [1]	None	None	1,034,000	1,034,000
Maryland [1]	145,000	449,000	893,000	1,487,000
Massachusetts [1]	None	None	6,184,000	6,184,000
Michigan	None	None	None	None
Minnesota	None	None	None	None
Mississippi	82,000	155,000	210,000	447,000
Missouri	103,000	642,000	818,000	1,593,000
Montana	23,000	108,000	152,000	283,000
Nebraska	74,000	109,000	506,000	689,000
Nevada	28,000	80,000	25,000	133,000
New Hampshire [1]	None	None	513,000	513,000
New Jersey	None	None	None	None
New Mexico	None	None	None	None
New York	None	None	None	None
North Carolina	45,000	228,000	366,000	639,000
North Dakota	None	None	None	None
Ohio	None	None	None	None
Oklahoma	None	None	None	None
Oregon	None	None	None	None
Pennsylvania	None	None	None	None
Rhode Island	36,000	None	817,000	853,000
South Carolina	64,000	174,000	124,000	362,000
South Dakota	None	None	None	None
Tennessee	6,000	80,000	47,000	133,000
Texas	489,000	592,000	634,000	1,715,000
Utah	19,000	57,000	192,000	268,000
Vermont	None	None	None	None
Virginia	None	241,000	275,000	516,000
Washington	210,000	379,000	804,000	1,393,000
West Virginia	28,000	253,000	177,000	458,000
Wisconsin	None	None	None	None
Wyoming [1]	35,000	47,000	146,000	228,000
Total	2,795,000	9,867,000	23,218,000	35,880,000

[1] States having permit fee equivalent to personal-property tax.

ESSENTIAL FACTS ON PERSONAL-PROPERTY TAXATION OF MOTOR VEHICLES SUMMARIZED

Outstanding results of this phase of the survey may be summarized as follows:

1. In 1932 there were levied against motor vehicles in the United States personal-property taxes in the estimated amount of approximately $44,081,000.

2. Of the motor vehicles subject to taxation, only about 60 percentare listed on the tax rolls.

3. The percentage of motor vehicles placed upon the rolls apparently runs from less than 35 percent in the State of Illinois to over 90 percent in Arizona, Connecticut, and Montana, and 100 percent in Maine, Maryland, Massachusetts, New Hampshire, Wyoming, and the District of Columbia.

4. There is a wide variation in the standard of assessment of motor vehicles in the various States.

5. Of the total tax levied, it is estimated that collections could not have exceeded $35,880,000 and they may have been considerably below this figure.

6. Because of difficulties in assessment and collection, the personal-property tax as ordinarily administered is not effectively applied to motor vehicles.

7. Seventeen States, in which there were, in 1931, 11,834,346, or 45.9 percent of the total motor vehicles, exempt motor vehicles entirely from taxation as personal property.

8. There are 31 States and the District of Columbia in which motor vehicles are subject to some form of taxation as personal property. In these States there were 13,959,757 motor vehicles registered, or 54.1 percent of all vehicles licensed.

9. The mean average tax levied against these vehicles was $3.16 and the median $3.04.

10. Of the States imposing personal-property taxes against motor vehicles, five States and the District of Columbia make their levies under special laws which insure that all motor vehicles operating are charged with and pay the personal-property tax. The total so levied in 1932 was $9,921,000. Located in these areas in 1931 were 1,700,930 motor vehicles or 6.6 percent of all the motor vehicles in the United States. This was an average of $5.83 per vehicle.

11. In the remaining 26 States, containing 12,258,827, or 47.5 percent of all motor vehicles in 1931, an ineffective attempt is made to tax motor vehicles under general property tax laws, the tax so levied in 1932 being $34,160,000, or $2.79 per vehicle.

FEDERAL MANUFACTURERS' EXCISE TAXES RELATING TO MOTOR VEHICLES

The first Federal manufacturers' excise taxes which were paid by motorists were imposed under the United States Internal Revenue Act of 1918, effective October 4, 1917. These taxes lasted until repealed on May 29, 1928. During the period of 10 years and 8 months in which the taxes were in force, they accumulated to a total of $1,119,931,631, or an average of about $105,000,000 a year. There were three groups of such taxes, as follows: (1) Automobile trucks and wagons, 3 percent on sales; (2) other automobiles and motorcycles, 5 percent on sales; and (3) automobile parts and accessories, 5 percent on sales.

For an interval of 4 years the motor-vehicle owner was free from Federal excise taxes. The Revenue Act of 1932 (approved June 6 and effective June 7, 1932) imposed certain manufacturers' excise taxes affecting the purchases of owners of motor vehicles. The new law, however, imposed six groups of taxes, as follows: (1) A gasoline tax of 1 cent per gallon; (2) a tax on lubricating oils of 4 cents per gallon; (3) on tires and inner tubes, taxes of 2¼ and 4 cents per pound, respectively; (4) on automobiles and motorcycles, 3 percent on sales; (5) on automobile trucks, 2 percent on sales; and (6) on automobile parts and accessories, 2 percent on sales. The tax on gasoline was increased to 1½ cents per gallon on June 17, 1933, and reverted to 1 cent on January 1, 1934.

These six taxes are paid, either directly or indirectly, by owners of motor vehicles, except for the fact that part of the excise taxes on gasoline and lubricating oils are paid by purchasers of these commodities for purposes other than for motor vehicles.

It will be observed that these taxes did not go into effect until June 7, 1932, with the result that the collections of 1932 represent but slightly more than a half-year period.

Table 22 gives a summary of the Federal excise-tax collections in 1932 and 1933, as reported and as adjusted to give as close approximations as possible to the amounts paid by the motorist in those years. The United States Bureau of Internal Revenue issues monthly reports showing the collections of the preceding month, which cover taxes assessed on the sales of the month preceding the month of collection. There is, in other words, a lag of a month between the collections as reported and the tax assessed on sales. The first column of figures in table 22 gives the collections of the calendar years 1932 and 1933. The second column gives the figures after adjustment by allowing for the lag of one month, as it was desired to show, as closely as practicable, the taxes as of the time when paid by the motorists. Thus the figures for the year 1932 include the collections of January 1933, and those for 1933 include the collections of January 1934.

TABLE 22. *Summary of Federal excise taxes relating to motor vehicles in 1932 and 1933*

CALENDAR YEAR 1932

Federal excise tax on	Collections	Assessment[1]	Assessment adjusted[2]
Gasoline	$62,839,827	$71,181,720	$68,247,200
Lubricating oil	7,067,119	8,388,330	8,000,000
Tires and inner tubes	7,515,071	8,112,487	8,112,487
Automobiles and motorcycles	1,221,263	4,996,000	4,996,000
Trucks	720,155	833,907	833,907
Parts and accessories	1,900,111	2,188,404	2,188,404
Total	81,293,846	98,700,848	92,377,998

CALENDAR YEAR 1933

Federal excise tax on	Collections	Assessment[1]	Assessment adjusted[2]
Gasoline	$181,125,987	$187,461,926	$171,152,700
Lubricating oil	22,289,624	22,638,019	18,643,800
Tires and inner tubes	23,836,119	24,917,117	24,917,117
Automobiles and motorcycles	22,475,888	22,412,568	22,412,568
Trucks	3,046,827	3,123,958	3,123,958
Parts and accessories	4,443,072	4,514,666	4,514,666
Total	257,217,517	265,128,254	244,821,809

[1] Collections as reported advanced 1 month to allow for lag.

[2] Figures for gasoline- and oil-tax assessments adjusted to allow for non-motor-vehicle usage.

The last column of table 22 gives the figures after adjustment for non-motor-vehicle use of gasoline and oil. In the case of gasoline the following method of approximation was used. From the data on gasoline taxes reported to the Bureau by the States it was found that in the last 6 months of 1932, 92 percent of the gasoline sold in the States was taxed by the States and sold for motor-vehicle use. For the calendar year 1933 the figure was 91.3 percent. It appeared reasonable to apply these percentages to the Federal gasoline-tax figures, although the gallonage taxed by the Federal Government was, in both periods, less than the gallonage reported to the Bureau as having been sold in the States.

In order to determine an approximate figure for the amount of the tax on lubricating oil assignable to motor vehicles, a ratio between the consumption of gasoline and the consumption of oil by motor vehicles was derived from results reported by other investigators,[7] and from the operating statistics of official cars used by employees of the Bureau of Public Roads in different parts of the country. The average ratio obtained as a result of this study was 28.24, i.e., 28.24 gallons of gasoline consumed to 1 gallon of oil. This ratio was not applied to the 1932 figures, as it was found to give inconsistent results, and a round figure of 2,000,000 gallons was assumed. In the case of the 1933 figures, the use of the ratio gave results which were entirely reasonable, indicating that approximately 82 percent of the oil taxed by the Federal Government was used by motor vehicles. In any event, however, the allowance for non-motor-vehicle use of oil is no more than a rough approximation.

The figures for the 2 years are not directly comparable, as those for 1932 cover only a little more than a half year, and the gasoline-tax rate was changed in 1933 from 1 to 1½ cents. Part of the increase, however, appears to be due to more effective administration of the law. The gallonage of gasoline taxed by the Federal Government in 1933 was much closer to the total reported by the States than was the case in the last half of 1932, indicating that early difficulties in enforcement have been eliminated. The same appears to be true in the case of the tax on lubricating oil.

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[7] National Motor Truck Analysis, by General Motors Truck Co., 1929; Bulletin 106, Automobile Operating Costs and Mileage Studies and Bulletin 111, Statistics of Motor Truck Operation in Iowa, Iowa Experiment Station, 1931 and 1933, and a 1932 survey of the American Petroleum Institute, unpublished.

PUBLIC BRIDGE AND FERRY TOLLS

The motorist in traveling over the highways must pay tolls on many bridges and ferries, both publicly controlled and privately owned. Although no data on this subject were obtained in the survey, it was decided to obtain, by a study of available records and reports, an approximation of the payments by motorists in 1932 in the form of public bridge and ferry tolls. The material obtained in this manner is by no means complete, and is probably several million dollars short of the true total.

On April 1, 1933, the number of toll bridges in operation was given as 317 in a list published by the American Toll Bridge Association in volume 1 of its 1933 proceedings. Among these there were 104 publicly owned bridges, of which 17 were interstate and 87 intrastate. Data on toll collections were obtained for 13 interstate bridges and 53 intrastate bridges, and also for a number of publicly owned ferries operated by the City of New York. Total collections reported were as follows:

Interstate bridges	$14, 154, 667
Intrastate bridges	2, 451, 220
Ferries	1, 593, 537
Total	18, 199, 424

PUBLICATION ON ROADSIDE IMPROVEMENT AVAILABLE

A limited supply of Miscellaneous Publication No. 191, "Roadside Improvement", is available for distribution, and single copies may be obtained by addressing the Bureau of Public Roads.

The publication discusses briefly roadside improvement in the Public Works highway program, methods of planning roadside improvement, estimated costs, and shows typical plans for roadside improvement. Numerous illustrations showing methods of treatment under different conditions are presented.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF SEPTEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
	$	$	$	$			$	$	$		$	$		$	$
Alabama	4,123,000	2,129,921	2,359,732	1,305,902		100.4	4,444,677	2,484,076		274.2	70,865	67,956	35.0	262,158	2,061,965
Arizona	3,878,555	1,338,712	2,905,253	2,796,788		211.3	1,516,515	1,045,802		83.7		566,328	30.3	35,964	772,384
Arkansas	3,374,167		1,278,390	994,798		45.1	2,436,220	2,149,632		126.0	150,354		3.4	79,383	
California	7,912,928	3,966,103	5,528,348	4,153,878		190.5	5,716,704	3,634,268		126.3		217,904	3.6	124,782	3,748,199
Colorado	3,437,265	2,424,504	2,854,473	2,834,213		137.7	883,839	564,151	214,960	28.7		935,784	50.4	38,901	1,273,759
Connecticut	1,404,213	607,500	139,823	139,823		3.0	1,385,153	1,213,805		27.8	584				607,500
Delaware	892,544	461,697	319,034	316,940		7.3	564,607	564,607		10.7		426,361	15.1	10,998	35,336
Florida	2,519,010	1,330,672	2,536,425	1,857,220		86.1	676,287	564,997		29.9	23,636		.6	73,157	1,330,672
Georgia	5,045,592	2,556,745	2,273,493	2,261,524		152.0	2,084,297	1,940,152		130.9	175,638		11.1	668,279	2,556,745
Idaho	2,166,858	1,131,910	1,262,385	1,216,551		136.0	863,704	830,103	14,243	45.1	38,585	104,173	6.1	81,619	1,013,494
Illinois	4,468,247	3,060,041	775,133	774,467		18.7	3,306,429	3,280,509		34.0	413,271	74,600	6.7		2,985,441
Indiana	5,018,921		1,274,253	1,274,253		50.0	3,054,294	3,053,606		84.9	278,689		3.9	412,372	
Iowa	5,027,830	2,217,361	3,160,840	3,025,900		178.9	2,510,801	1,981,330	326,600	103.8		1,097,800	110.1	20,600	792,961
Kansas	5,044,802	2,558,837	3,897,490	3,890,538		359.2	1,439,931	1,152,953		45.6	1,311	1,209,038	231.0		1,349,800
Kentucky	3,751,605	1,527,324	2,315,327	2,290,576		182.8	1,472,160	1,290,368		69.0	162,225	281,009	39.0	8,436	1,246,315
Louisiana	2,681,152	1,380,419	1,121,934	1,120,701		42.2	2,034,333	1,527,682		36.1	23,133		.7	9,636	1,380,419
Maine	1,617,560	793,644	841,313	830,433		29.9	818,723	681,689	112,347	17.2		148,351	3.1	105,438	532,946
Maryland	1,782,263	289,610	527,930	518,281		10.5	576,405	576,405		10.7	602,702	106,226	13.8	84,874	183,383
Massachusetts	1,101,716		936,557	647,306		29.2	480,783	377,083		3.6				77,327	
Michigan	6,113,389	3,226,284	1,431,900	1,431,900		64.2	4,483,925	4,431,875	3,050	204.0	249,614	408,300	19.3		2,814,934
Minnesota	4,561,011	2,642,244	3,655,649	3,597,604		685.3	2,153,036	949,991	1,203,045	131.8	8,327	757,148	110.9	5,089	682,050
Mississippi	3,489,337	2,301,148	1,816,051	962,859		93.1	3,568,025	1,962,414		190.0	320,298	742,188	68.5	243,767	1,558,960
Missouri	5,237,532	2,778,183	3,497,375	2,983,537		149.7	2,216,193	1,985,348	198,171	59.5	92,668	758,845	36.1	175,979	1,821,168
Montana	4,463,849	2,714,208	4,052,919	3,768,707		310.9	1,093,371	684,688		84.5		906,887	93.3	10,454	1,807,321
Nebraska	3,914,481	1,982,182	3,173,604	2,402,926		247.8	2,172,670	1,510,380		120.9	1,176	775,559	30.4		1,206,623
Nevada	2,909,387	1,350,356	1,978,207	1,978,207		212.2	970,753	927,426		52.6		184,302	11.6	3,754	1,166,053
New Hampshire	725,739	484,731	602,305	595,769		9.7	142,375	129,970		1.5		12,479	.3		472,252
New Jersey	3,099,371	951,379	496,970	496,384		14.7	2,670,159	2,515,195		32.4				87,792	951,379
New Mexico	2,846,648	1,470,850	2,842,995	2,699,066		270.5	81,498	81,498		3.7		750,297	64.1	66,083	720,553
New York	10,271,846	2,872,521	3,504,275	2,897,890		78.9	10,758,059	7,319,798	925,400	201.3		1,784,900	34.5	54,158	162,221
North Carolina	4,761,147	2,420,471	2,137,710	1,674,633		212.3	2,604,028	2,360,445		401.2	304,274	512,884	75.3	421,795	1,907,587
North Dakota	2,902,224	1,469,483	2,475,087	2,258,757		845.7	702,661	502,526		137.2	96,107	94,208	54.2	44,834	1,375,276
Ohio	7,277,758	3,539,256	5,085,584	4,840,143		129.5	2,543,440	2,376,483		62.4				61,132	3,539,256
Oklahoma	4,608,399	2,342,590	2,914,440	2,877,382		219.7	1,354,993	1,348,757		81.1	282,201		14.7	100,059	2,342,590
Oregon	3,053,448	1,548,906	2,528,201	2,289,519		142.1	820,324	726,446		40.8	13,619	846,168	40.3	23,864	702,738
Pennsylvania	6,691,194	4,554,082	2,415,674	2,409,638		64.9	4,441,422	4,096,104		66.7	115,565	1,779,873	40.7	69,887	2,774,209
Rhode Island	979,367	464,572	996,030	933,162		20.5								46,205	464,572
South Carolina	2,729,583	1,385,477	775,112	775,112		61.7	1,933,498	1,914,334		174.4		117,078	10.0	40,137	1,268,399
South Dakota	3,005,739	1,523,821	1,563,480	1,464,727		276.1	1,647,395	1,286,667		232.1	247,334		42.6	7,011	1,523,821
Tennessee	4,246,309	2,105,453	2,998,525	2,478,516		124.5	1,607,935	1,517,177		55.8	132,255	174,299	13.3	118,360	1,931,154
Texas	11,588,643		8,427,536	7,574,419		765.9	3,422,779	3,347,513		246.3	223,868		2.4	442,843	
Utah	2,374,205	1,066,345	1,793,409	1,761,824		163.0	1,022,467	583,284	375,500	83.2		405,280	40.2	29,097	285,565
Vermont	928,184	466,042	528,553	525,272		21.7	420,090	392,242		23.1	10,670	173,201	11.1		292,842
Virginia	3,708,379	1,882,693	2,497,668	2,439,306		120.3	1,078,656	969,035		18.6	68,466	233,490	20.7	231,573	1,649,203
Washington	7,057,934	1,553,206	1,841,533	1,833,822		76.9	1,336,098	1,173,045	163,053	34.3	46,000	226,793	5.8	5,067	1,163,360
West Virginia	2,013,405	1,140,167	990,894	990,894		33.8	1,163,303	999,892	143,948	43.2	9,320	618,057	21.6	13,299	378,162
Wisconsin	4,615,429	2,223,827	3,182,208	3,103,546		148.2	1,463,735	1,431,100		80.7	63,886	202,500	12.5	16,897	2,021,327
Wyoming	2,250,663	1,143,856	1,858,880	1,647,113		376.5	1,075,740	595,976	431,726	159.5		377,188	43.7	7,574	334,942
District of Columbia															
Hawaii	1,683,956	598,778	196,115	144,003		10.4	1,824,472	1,471,913		28.5	66,000		.7	2,040	598,778
TOTALS	185,356,784	81,978,111	108,617,022	98,136,729		7,921.5	97,038,962	78,504,740	4,112,043	4,344.5	4,292,641	18,077,454	1,482.7	4,422,674	59,758,614

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF SEPTEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Work Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
	$	$	$	$			$	$			$	$		$	$
Alabama	2,175,100	1,064,961	570,864	570,864		13.0	1,476,698	1,476,698		46.2	87,753		3.6	39,784	1,064,961
Arizona	807,982	305,191	480,317	480,317		11.4	139,134	139,134		1.6	138,121	6,593	.4	50,410	298,599
Arkansas	1,889,534		693,583	640,479		19.8	1,036,599	975,231		23.7	273,824		.4		
California	4,213,986	1,983,052	2,591,780	2,288,212		33.1	2,261,406	1,853,388		19.6		50,000	.6	72,387	1,933,052
Colorado	1,718,633	190,000	1,685,280	1,636,065		33.6	79,446	79,446		1.5	3,122	23,454	2.0	-	166,545
Connecticut	802,407	426,500	725,645	722,110		8.5	80,297	80,297		1.7					426,500
Delaware	477,681	230,849	150,761	142,479		1.4	325,201	325,201		6.0	4,919	48,713	.6	5,081	182,136
Florida	1,405,008	665,336	774,410	567,359		8.4	860,130	829,288		9.8	8,361		.8		665,336
Georgia	2,724,620	1,278,373	710,948	710,679		31.1	1,059,735	1,059,735		32.9	309,919		3.4	644,287	1,278,373
Idaho	1,197,329	321,126	524,411	513,249		11.3	631,329	612,538	2,643	8.3				72,042	318,483
Illinois	7,692,483	2,515,835	2,454,700	2,441,992		31.7	4,730,469	4,730,469		38.5	418,997		1.4	101,026	2,515,835
Indiana	4,416,651		801,788	800,116		20.8	3,017,316	3,017,316		47.9	265,006		3.9	334,213	
Iowa	2,614,472	1,311,000	1,220,188	1,171,315		36.2	1,240,456	1,162,300		16.4	278,100	47,500	10.5	2,757	1,263,500
Kansas	2,522,401	1,279,419	1,802,794	1,797,250		31.9	865,988	721,135		5.2	4,016	29,255	3.2		1,250,163
Kentucky	1,927,828	954,578	607,381	597,891		16.6	749,095	745,318		12.8	455,985	39,975	3.5	128,635	914,603
Louisiana	1,748,577	744,560	513,079	513,079		11.5	911,517	884,923		14.2	59,145		1.4	291,429	744,560
Maine	909,878	490,045	505,407	503,201		11.3	333,585	332,689		5.4				73,988	490,045
Maryland	891,132	452,514	235,592	231,442		2.1	152,692	152,692		2.1	268,000		.4	238,998	452,514
Massachusetts	5,007,199		232,729	191,184		4.2	4,594,207	4,569,231		12.3	127,088			119,696	
Michigan	3,438,781	1,613,142	980,695	978,545		12.9	2,593,275	2,453,525	127,250	30.0	6,461	171,300	2.4	250	1,314,592
Minnesota	3,719,143	1,421,494	1,980,448	1,953,111		79.2	1,358,979	1,217,322	141,657	23.2		174,106	13.4	548,711	1,105,731
Mississippi	1,744,669	885,057	350,579	338,120		11.5	712,036	712,036		26.6	231,581	102,253	8.7	462,932	782,804
Missouri	4,019,501	1,543,435	1,366,141	1,329,518		42.1	2,456,038	1,945,070	54,043	15.8	163,917	74,786	3.9	580,996	1,414,606
Montana	1,115,962	113,092	962,687	962,687		27.0	97,687	97,687		5.1	45,318		4.5	10,270	113,092
Nebraska	1,957,240	991,091	650,794	645,868		20.0	1,287,538	1,264,538	23,000	13.1		42,789	1.2	46,834	925,302
Nevada	500,051	100,000	309,005	309,005		6.2	195,019	172,014		2.6				19,031	100,000
New Hampshire	706,640	242,366	521,029	505,545		10.1	230,860	184,658	46,202	7.2				16,438	196,164
New Jersey	3,190,118	1,809,500	709,759	709,447		5.3	2,451,433	2,397,300		17.5				83,370	1,809,500
New Mexico	1,674,158	735,425	1,103,883	1,103,883		28.9	429,914	429,914		5.6		184,265	5.1	140,361	551,159
New York	8,449,487	4,203,000	1,969,353	1,945,287		22.7	6,961,394	6,355,446	113,200	41.9		620,500	3.3	148,754	3,469,300
North Carolina	2,380,573	1,210,235	1,434,604	1,431,675		54.9	508,662	507,170		20.5	326,251	61,179	6.9	115,477	1,149,057
North Dakota	1,451,112	734,742	701,209	700,447		26.6	347,115	347,115		18.1	403,551		15.0		734,742
Ohio	4,335,686	2,359,503	2,955,960	2,655,336		39.3	1,891,560	1,650,877		20.0				29,472	2,359,503
Oklahoma	2,304,200	1,171,295	1,124,918	1,122,215		26.3	871,168	870,389		16.3	140,326		2.7	171,270	1,171,295
Oregon	1,526,724	774,454	1,049,450	1,033,325		19.8	428,289	428,289		8.0	30,841		.6	34,269	774,454
Pennsylvania	4,854,988	2,397,703	2,616,581	2,558,601		44.9	1,766,237	1,739,181		13.6	440,769	220,600	5.3	116,436	2,177,103
Rhode Island	579,625	255,000	393,038	393,038		6.4	148,206	148,206		1.0				38,381	255,000
South Carolina	1,364,791	692,738	379,077	379,077		11.5	731,716	731,312		28.9	79,817	4,464	2.2	174,586	688,275
South Dakota	1,502,870	761,911	814,433	814,433		25.4	330,846	330,846		13.3	75,873		3.0	281,717	761,911
Tennessee	2,123,155	1,121,790	1,234,458	1,234,267		18.6	621,513	621,513		6.4	186,439		2.4	80,937	1,121,790
Texas	6,642,863		2,516,295	2,429,256		79.1	2,853,752	2,838,639		33.5	963,221		5.5	411,747	
Utah	771,826	533,173	646,716	630,627		16.5	38,792	26,700	10,900	1.7		76,929	2.9	114,499	445,343
Vermont	500,509	240,611	288,685	280,343		8.9	237,498	220,166		5.7					240,611
Virginia	2,008,458	941,347	1,070,996	1,045,792		23.4	801,029	614,138		1.7	215,319	49,828	3.2	133,209	891,519
Washington	1,977,260	776,603	1,577,681	1,560,710		29.4	377,994	377,994		3.0		99,842	3.0	38,556	676,761
West Virginia	1,342,270	570,085	252,561	252,561		5.7	1,088,506	1,048,232	15,928	15.2		10,437	.4	41,477	543,720
Wisconsin	2,684,067	1,235,459	1,695,722	1,677,164		40.8	949,352	927,290		11.0	142	66,146	3.0	79,471	1,169,313
Wyoming	1,125,332	571,928	603,618	603,114		14.7	526,648	522,218	3,845	9.9					568,083
District of Columbia	968,235	243,460	610,011	610,011		3.9	523,344	357,994	165,350	2.2		63,730	.5	230	14,381
Hawaii															
TOTALS	116,103,695	44,462,978	50,152,043	48,712,291		1,099.9	58,361,700	55,284,808	704,018	724.7	6,012,182	2,268,644	135.2	6,094,414	41,490,316

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF SEPTEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
	$	$	$	$			$	$			$			$	$
Alabama	2,072,033	1,064,960	89,081	89,081		5.7	1,482,769	1,482,769		114.5	490,024		29.3	10,159	1,064,960
Arizona	525,423	998,032	114,319	114,154		7.2	413,007	406,045		35.1				5,223	998,032
Arkansas	1,484,634		162,892	162,798		43.6	1,057,917	1,057,917		105.2	55,005		.4	208,914	
California	3,430,440	1,983,051	2,152,721	1,781,435		55.3	1,774,376	1,515,911		122.7	11,769		.7	171,324	1,983,051
Colorado	1,713,632	871,502	1,515,298	1,481,932		150.7	793,196	208,000	189,868	143.5		63,239	8.6	23,700	618,395
Connecticut	659,120	420,868					664,916	659,120		14.5					420,868
Delaware	443,363	230,849	20,325	20,325			260,326	260,326		14.0		191,978	43.1	167,712	38,871
Florida	1,307,816	665,335	755,468	752,875		53.7	525,378	525,378		21.3				29,563	665,335
Georgia	2,320,973	1,278,373	580,820	580,820		41.2	812,927	812,927		75.3	493,638		29.9	433,589	1,278,373
Idaho	1,121,562	824,450	923,716	870,738		117.9	316,907	250,824	50,000	38.7		67,844	8.8		706,606
Illinois	5,410,040	3,345,525	1,083,445	1,087,838		81.6	4,093,768	4,093,768		237.2	213,621	26,342	9.3	14,313	3,319,183
Indiana	602,271						534,106	534,106		68.9	68,165		7.9		
Iowa	2,413,358	1,590,000	1,014,215	972,900		123.8	1,525,282	1,350,150	3,800	198.2	46,750	328,100	127.2	43,558	1,258,100
Kansas	2,522,401	1,279,419	959,962	959,721		92.9	1,562,680	1,562,680		69.7		454,516	87.9		824,903
Kentucky	1,837,926	1,336,409	1,418,657	1,407,032		172.9	429,277	427,892		42.8		398,825	46.4	3,001	937,584
Louisiana	1,333,862	838,953	322,703	322,423		20.9	873,530	873,530		25.6	73,175		12.8	124,734	838,953
Maine	842,479	427,897	906,666	822,202		78.4	236,549	13,000	223,549	22.3		41,075	3.8	7,277	163,272
Maryland	891,132	1,067,934	486,235	486,235		37.6	377,919	363,993		25.5	18,643	245,268	13.5	22,262	822,667
Massachusetts	488,185		367,128	367,128		11.5	102,613	102,613		3.7				18,444	
Michigan	3,184,057	1,613,142	713,750	713,750		57.2	2,397,130	2,382,230		168.8		58,400	1.0	88,077	1,554,742
Minnesota	2,375,415	1,361,813	1,525,211	1,508,312		165.9	808,755	783,287	25,468	55.1	5,000	61,843	1.5	79,816	1,274,503
Mississippi	1,744,669	354,022					1,246,917	1,246,917		130.2	323,876		36.0	173,876	354,022
Missouri	2,923,273	1,852,122	2,156,918	2,148,405		443.1	680,986	680,870		57.1	4,361	404,810	202.3	89,637	1,447,312
Montana	1,859,937	942,434	1,734,924	1,734,924		216.7	133,454	123,005		9.3		57,934		2,008	884,500
Nebraska	1,957,240	991,091	760,551	759,498		124.4	1,562,693	1,164,997	397,447	162.1		88,725	141.7	32,745	504,919
Nevada	1,136,479	852,000	960,180	960,180		96.7	199,060	128,692		12.5	13,239	129,750	37.9	34,368	722,250
New Hampshire	477,460	242,365	352,652	311,828		18.3	165,556	165,556		7.4		43,166	2.1	76	199,199
New Jersey	56,550	460,000	56,550	56,550		.5									460,000
New Mexico	1,272,129	735,425	735,923	735,923		142.1	510,192	510,192		81.3				26,014	735,425
New York	3,608,768	4,252,400	1,627,271	1,524,396		42.0	3,677,550	2,073,875	899,900	85.5		1,134,000	46.1	10,497	2,218,500
North Carolina	2,380,573	1,210,235	1,115,121	1,114,722		84.0	975,782	975,782		137.8	240,732	42,705	20.4	49,336	1,167,530
North Dakota	1,451,112	734,742	289,278	289,278		68.2	404,321	404,321		133.0	383,181		158.0	374,332	734,742
Ohio	3,871,148	1,966,253	2,423,807	2,232,757		256.7	1,698,470	1,578,403		48.1	55,500		.1	4,488	1,966,253
Oklahoma	2,304,199	1,171,295	411,588	408,034		93.3	1,908,852	1,835,593		175.8	45,872		8.5	14,700	1,171,295
Oregon	1,526,724	774,454	1,177,613	1,070,482		83.2	533,275	452,280		25.3		157,683	9.9	3,962	616,771
Pennsylvania	7,344,822	2,639,003	3,201,919	3,201,508		325.9	4,289,412	4,103,850	102,899	332.6	39,465	128,267	8.7		2,407,837
Rhode Island	439,716	295,000	185,058	185,058		15.8	227,407	227,407		17.3				27,251	295,000
South Carolina	1,364,791	692,739	474,065	474,065		45.3	768,414	768,414		99.3	100,851	66,601	15.4	21,462	626,137
South Dakota	1,502,370	761,911	801,964	801,964		231.6	376,779	376,779		116.1	311,279		100.0	12,848	761,911
Tennessee	2,123,155	1,075,748	842,318	835,182		69.1	1,035,213	1,035,213		75.4	112,129		2.4	140,631	1,075,748
Texas	6,012,518		4,155,331	3,749,970		590.1	2,230,251	2,075,950		175.5	112,500		.3	74,098	
Utah	1,043,677	533,173	871,007	811,709		133.1	365,511	225,945	105,224	71.1		72,298	14.0	11,022	355,651
Vermont	433,380	241,354	158,568	150,200		11.5	327,488	288,680		25.2		71,593	4.6		169,761
Virginia	1,639,920	941,347	1,137,562	1,095,192		155.6	575,744	546,855		49.7	12,950	40,373	4.6	44,923	900,974
Washington	1,080,673	776,603	665,204	647,946		45.4	404,261	404,261		18.3	27,739		3.9	727	776,603
West Virginia	1,118,559	570,083	116,819	116,819		4.4	865,194	858,116		49.5	64,518		3.2	79,107	570,083
Wisconsin	2,425,335	1,482,551	1,811,660	1,706,843		121.9	527,251	508,621		45.8	209,921	154,305	10.5		1,328,246
Wyoming	1,125,332	571,928	956,796	935,694		139.3	132,948	129,720		8.9		15,352	4.1	59,918	556,576
District of Columbia	950,234	730,382	476,040	476,040		5.0	572,104	468,117	103,987	3.5		93,911	1.7	6,077	532,434
Hawaii	137,106	351,000					177,718	177,718		4.9				9,388	351,000
TOTALS	92,539,521	49,400,172	44,774,799	43,037,366		4,881.2	47,626,131	43,207,595	2,102,142	3,762.1	3,533,903	4,638,903	1,268.5	2,760,657	42,659,127

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF SEPTEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Work Funds	1935 Public Work Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
	$	$	$	$			$	$			$	$		$	$
Alabama	8,370.133	4,259,842	3,019,677	1.965,847		119.1	7.404,144	5.443,543		434.8	648,642	67.956	67.9	312.101	4,191.886
Arizona	5,211.960	2,641,935	3,499,889	3,391.260		229.9	2.073.656	1.590.931		120.4	138,121	572,921	30.6	91.598	2.069,014
Arkansas	6,748,335	3,428,049	2,134,864	1.798,075		108.5	4,530,736	4,182.780		255.0	479,182		4.2	288.297	3.428.049
California	15.607,354	7.932.206	10.272,849	8,223.525		278.9	9.752.487	7.003.566		268.5	11.769	267,904	4.8	368.494	7,664.302
Colorado	6,874,530	3.486.006	6,055,051	5,952,210		322.0	1.756,481	851.597	404,829	173.7	3,122	1.022.478	60.9	67.601	2,058,699
Connecticut	2.865,740	1.454.868	915,469	911.933		11.5	2,130,366	1,953,223		44.0	584				1.454,868
Delaware	1.819,088	923,395	490.619	430.244		8.7	1,150.134	1.150.134		30.7	4,919	667,052	58.8	183.791	256,344
Florida	5.231.834	2,661,343	4,066,303	3.177,454		148.2	2.061.735	1.919.663		61.0	31.997		1.4	102,720	2,661,343
Georgia	10,091,185	5.113,431	3.565,260	3.553.023		224.3	3,956,958	3.812.813		239.2	979.194		44.4	1,746,155	5.113.491
Idaho	4,486.249	2,277,486	2,710.512	2.600.538		265.2	1,811,940	1.693.464	66.886	92.1	38.585	172,017	14.9	153,661	2,038.583
Illinois	17.570.770	8,921,401	4,313.278	4,304.297		132.0	12.130.666	12.104,746		309.7	1.045,889	100,942	17.4	115.839	8,820.459
Indiana	10,037.343	5.083,963	2,076,041	2,074.369		70,8	6.605.715	6,605,028		201.7	611.860		15.7	746,586	5,083,963
Iowa	10.055,660	5.118.361	5.395,243	5.170,115		338.8	5.276.539	4.493,780	330.400	318.3	324.850	1.473.400	247.8	66,915	3.314.561
Kansas	10,089.604	5.117.675	6,660,246	6,647.509		484.0	3,868.600	3,436,768		120.5	5.327	1.692,808	322.1		3.424.867
Kentucky	7.517.359	3.818,311	4,341.365	4,295,499		372.3	2.650.532	2.463.578		124.6	618,210	719,810	88.9	140,073	3,098,501
Louisiana	5,828,591	2,963.932	1.957.716	1,956,203		74.6	3,824,380	3,291.136		76.0	155.453		15.0	425,799	2,963,932
Maine	3,369,917	1.711.586	2,253,385	2,155,836		119.6	1.388,857	1,027,378	335,896	44.9		189,426	6.8	186,703	1.186.264
Maryland	3.564,527	1.810.058	1.249.757	1,235,958		50.2	1,107.016	1,093,090		38.3	889,345	351.494	27.7	346.134	1.458.564
Massachusetts	6,597,100	3,350.474	1,536,414	1.205,618		44.9	5,177,603	5.048.927		24.6	127,088			215,466	3,350,474
Michigan	12.736.227	6,452.568	3,126,345	3,124,195		134.3	9,474.330	9,267.630	130,300	402.8	256.075	638.000	22.7	88,327	5.684.268
Minnesota	10.656,569	5.425,551	7,151.309	7,059.027		930.4	4,320,770	2,950,600	1.370.170	210.1	13,327	993.098	125,8	633.616	3.062,283
Mississippi	6.978.675	3.540,227	2,166,630	1.300,978		104.6	5,526,977	3.921.367		346.8	875.755	844.440	113.2	880,575	2.695,787
Missouri	12.180.306	6.173,740	7.020.434	6,461.460		634.8	5.353,217	4.611,288	252.213	132.3	260.946	1,238,441	242.3	846,612	4.683,086
Montana	7.439.748	3.769,734	6.750.530	6,466.318		554.5	1,324,512	905.380		99.0	45.318	964,821	97.8	22,732	2.804,913
Nebraska	7.828,961	3.964.364	4,584,948	3,808,291		392.2	5,022,902	3.939.915	420.447	296.1	1,176	907.074	173.3	79.579	2.636.844
Nevada	4.545.917	2,302,356	3.247.393	3.247.393		315.1	1.364,832	1.228.132		67.7	13.239	314,052	49.5	57.153	1.988,304
New Hampshire	1,909,839	969.462	1.475.986	1.413.142		38.1	538.791	480.184	46.202	16.1		55,645	2.4	16.514	867.615
New Jersey	6.346.039	3,220,879	1.263.279	1.262.382		20.5	5,121,593	4,912,495		49.9				171.162	3,220.879
New Mexico	5.792,935	2,941,700	4,682.802	4.538.872		441.5	1,021.605	1.021.605		90.6		934,562	69.3	232,458	2.007.138
New York	22.330,101	11,327,921	7,100,899	6.367.573		143.7	21.397.002	15.749.120	1.938,500	328.6		3.539.400	83.9	213,408	5,850,021
North Carolina	9.522.293	4,840.941	4,687,435	4.221.030		351.2	4,088,473	3.843.397		559.5	871.258	616.767	102.6	586,608	4.224,173
North Dakota	5.804,448	2,938,967	3.465,574	3.248,481		940.5	1.454,096	1.253.961		283.3	882.839	94,208	227.2	419,166	2,844.759
Ohio	15,484,592	7.865.012	10.465.351	9.728,236		425.6	6,133.470	5.605.763		130.5	55.500		.1	95,092	7.865.012
Oklahoma	9.216,798	4.685,180	4.450,946	4.407.631		339.3	4.135.013	4,054,739		273.2	468,400		25.9	286.028	4.685,180
Oregon	6,106.896	3.097.814	4.755.264	4,393,326		245.1	1.781.889	1.607.016		74.1	44.460	1.003,851	50.9	62,095	2.093.963
Pennsylvania	18,891,004	9.590,788	8,234,174	8,169.747		435.7	10.497,072	9.939.135	102.899	413.0	595,800	2.128,740	54.7	186.323	7.359.149
Rhode Island	1,998,708	1.014.572	1.574.126	1.511.259		42.8	375.613	375.613		18.3				111.836	1,014.572
South Carolina	5.459.165	2,770,954	1.628.254	1.628,254		118.4	3.433,628	3.414.059		302.6	180,667	188.143	27.5	236.185	2.582,811
South Dakota	6,011.479	3.047.643	3.179.877	3.081.124		533.1	2.355.019	1,994.292		361.5	634,487		145.6	301,576	3,047,643
Tennessee	8,492.619	4.302.991	5.075.301	4.547.965		212.3	3.264.661	3.173.903		137.6	430.823	174.299	18.1	339.928	4.128.691
Texas	24,244.024	12.291.253	15.099.162	13,753.645		1.435.2	8.506,783	8.262.102		456.3	1.299.588		8.2	928,689	12,291.253
Utah	4.194.708	2.132.691	3.311.133	3.204.161		312.6	1.426.769	835,929	491,624	156.0		554.507	57.1	154,618	1.086.560
Vermont	1.867.573	948,007	975.806	955.814		42.1	985.076	901.088		54.0	10.670	244.794	15.7		703.213
Virginia	7,416.757	3.765,387	4,706.225	4,580,290		299.2	2,455,428	2.130.028		70.1	296.735	323.691	28.5	409.704	3,441,696
Washington	6.115.867	3.106,412	4,084.417	4,042,477		151.7	2.118,353	1.955.300	163.053	55.5	73.739	326.635	12.7	44,351	2,616.724
West Virginia	4.474.234	2,280.335	1,360.275	1,360,275		43.8	3.117,003	2.906.240	159,876	107.9	73.837	628.494	25.3	133,882	1.491.965
Wisconsin	9.724.881	4,941,837	6.689.591	6.487,552		310.9	2,940.337	2,867,011		137.4	273.950	422.951	26.0	95.368	4.518.886
Wyoming	4.501.327	2,287.712	3.419,294	3.185.921		530.5	1.735.336	1.247.914	435.571	178.4		392.540	47.9	67.492	1,459.601
District of Columbia	1.918,469	973.842	1,086.051	1.086.051		9.0	1.095.448	826.111	269.337	5.7		157.640	2.2	6.307	546,865
Hawaii	1.871.062	949.778	196,115	144.003		10.4	2,002.190	1.649.631		33.4	66.000		.7	11.428	949.778
TOTALS	394.000.000	200.000.000	203,543.864	189,886.386		13,902.6	203,026.793	176.997,143	6.918.203	8,831.3	13.838,726	24.985.001	2.886.4	13.277.745	168,096,796

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PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

Volume 15, No. 9 November 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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EFFECT OF MIXING TIME ON QUALITY OF CONCRETE PRODUCED IN LARGE MIXERS

BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

Reported by WILLIAM A. BLANCHETTE, Highway Engineer

STUDIES have been conducted by the Bureau of Public Roads at two concrete central-mixing plants to determine the effect of the length of the mixing time on the uniformity of distribution of the ingredients and on the strength of the concrete as mixed in large-capacity mixers. The grinding of the aggregates during the mixing action was also studied.

These studies show that the mixers did not distribute the materials uniformly throughout the batch; the degree of uniformity of distribution of materials was not changed by changes in mixing time from 1 to 4 minutes; and such changes in mixing time did not materially affect the strength. Increases in mixing time increased the amount of grinding of fine aggregate.

TESTS AT PLANT 1 DESCRIBED

The tests at plant 1 were made with a stationary no. 84–S mixer, 96 inches in diameter and 78 inches long and revolved 10.5 times per minute. The proportions of the aggregate by dry weight were as follows:

	Pounds
Cement	1, 750
Fine aggregate	4, 495
Coarse aggregate	6, 403
Net water	1, 162
Absorbed water	100

These quantities gave a batch with an absolute volume of 94 cubic feet.

The sand used as fine aggregate was analyzed as follows:

Sieve number:	*Percent retained*
4	4. 0
8	18. 9
14	32. 9
28	51. 4
48	82. 4
100	96. 0

The coarse aggregate consisted of two sizes of gravel combined to give the following analysis:

Screen opening:	*Percent retained*
2½ inches	0. 0
1½ inches	0. 0
¾ inch	35. 3
⅜ inch	73. 9
No. 4	96. 5

Strength specimens were cured in a moist room and broken at 28 days. Beams were broken by 3-point loading, 1 break being obtained on each beam.

In the tests at plant 1 batches of concrete were sampled after being mixed for 1, 2, 3, and 4 minutes. Samples from 5 different batches were obtained for each mixing time with the exception of 3 minutes. Six batches were sampled after 3 minutes of mixing. As each batch of concrete was being discharged from the mixer, three 200-pound samples were obtained; one at the beginning of the discharge, one in the middle, and one at the end of the discharge period. From a 200-pound sample, one slump test was made, one 30-pound sample was analyzed to determine the proportion of each ingredient contained in it, and two 6- by 12-inch cylinders and one 6- by 6- by 21-inch beam were made. This made 3 uniformity tests, 6 cylinders and 3 beams for each batch or a total of 15 uniformity tests, 30 cylinders and 15 beams for each of the 1-, 2-, and 4-minute mixing periods and 18 uniformity tests, 36 cylinders and 18 beams for the 3-minute mixing period.

ANALYSES TO DETERMINE COMPOSITION OF SAMPLES REQUIRE CAREFUL PROCEDURE

Conclusions as to the uniformity of distribution of materials were reached by determining the content of cement, water, fine aggregate and coarse aggregate in the 30-pound samples on a percentage basis and comparing them with the corresponding percentages for the batch as a whole. Materials for the batch as a whole were accurately weighed and variations of the coarse and fine aggregates from the limiting no. 4 and no. 100 sieves determined. The reasons for the latter determinations will appear in the following paragraphs.

The percentages of materials in a 30-pound sample of concrete were determined as follows. The sample of wet concrete was first weighed in air and then in water. The sample was then placed in a special washing machine[1] which washed out the cement and other material passing the no. 100 sieve and separated the aggregate into fine and coarse material by a no. 4 sieve. The fine and coarse aggregate were each weighed in water and after applying several correction factors the dry weight of coarse aggregate and dry weight of fine aggregate and cement were determined by the following formula:

$$\text{Dry weight of material} = \frac{\text{Specific gravity} \times \text{immersed weight}}{\text{Specific gravity} - 1}$$

The factors referred to were corrections on account (1) the grinding of aggregate in mixing, (2) material in the coarse aggregate (as weighed for the whole batch) finer than the no. 4 and no. 100 sieve, and (3) material in the fine aggregate (as weighed for the whole batch) coarser than the no. 4 sieve and finer than the no. 100 sieve. The correction for aggregate finer than the no. 100 sieve was necessary since the material washed through the no. 100 sieve after being corrected for aggregate content (including that resulting from grinding) was considered as the cement content of the sample.

The difference between the weight of the immersed sample and combined weights of immersed aggregate, after proper correction gave the immersed weight of cement.

The difference between the weight of the sample in air and the dry weights of cement, fine aggregate, and coarse aggregate gave the amount of water in the sample.

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[1] Washing Machine Designed for Use in Determining Constituents of Fresh Concrete, PUBLIC ROADS, vol. 13, no. 9, November 1932.

METHOD OF DETERMINING CORRECTION FACTORS FOR THE GRINDING ACTION DESCRIBED

It was found that grinding may or may not take place during the mixing of a batch. The extent of grinding is probably affected by some or all of the following factors: Type and gradation of both fine and coarse aggregate, proportion of each in mix, number of revolutions of mixer drum, ratio of capacity of mixer drum to volume of batch, and the mixing action in the drum including the amount of drop of the aggregates. There is no simple method by which the amount of grinding that takes place during the mixing of a batch of concrete can be determined with precision. Even though the entire mixed batch could be analyzed to determine the amount of material finer than the no. 100 sieve, corrections must be made for the amount of each ingredient passing this sieve before the mixing. These corrections are not exact since they are based on samples that are only a small part of the ingredients in the batch.

Grinding is indicated when analyses of samples show consistently a greater amount of cement (material passing no. 100 sieve) in the samples after mixing than is indicated by the batch proportions, proper allowance being made for the aggregate passing the no. 100 sieve before mixing. Where grinding was indicated, tests were made to determine the percentage of both coarse and fine aggregate so reduced in size during the mixing action that it passed the no. 100 sieve.

Coarse aggregate and water in the same relative proportions as in the batches being sampled were placed in the mixer. At the end of 1, 2, 3, and 4 minutes of mixing 30-pound samples were removed from the mixer and washed in the washing machine. The percentage of aggregate passing the no. 100 sieve was determined. The test was repeated using fine aggregate and water and again using fine aggregate, coarse aggregate, and water. Several determinations were made with each combination. These tests showed that with coarse aggregate and water there was no appreciable grinding for any mixing period used. The same was true for the fine aggregate and water mixture. For the fine and coarse aggregate and water mixture the amount of aggregate passing the no. 100 sieve, in excess of that passing before mixing, was appreciable and increased with the length of the mixing period.

These facts indicate that the mixer drum acts as a ball mill. Particles of sand are pulverized by the particles of coarse aggregate falling on them. There appeared to be no pulverizing of the fine particles of coarse aggregate by the larger particles and there appeared to be no wearing away of either aggregate due to friction with the drum, blades, and buckets.

As a further check in establishing the amount of grinding the following procedure was followed. The analysis of every sample of concrete showed the percentage variation (plus or minus) of the cement, fine and coarse aggregate and water from the original proportions of each of these ingredients. The complete analysis of all samples for all mixing periods showed a consistent plus variation for what was called cement, and a consistent minus variation for fine aggregate. There was no evidence that the coarse aggregate was ground up to pass either the no. 4 or no. 100 sieves. From the average of all variations in cement and all variations in fine aggregate for each mixing period, the apparent gain in cement due to grinding of fine aggregate was computed for each mixing time. Correction factors as computed in this manner checked closely with those determined as previously outlined. The average of the factors determined by both methods was then applied in recomputing the variations in all samples.

VARIATIONS IN UNIFORMITY FOUND IN ALL BATCHES

Table 1 contains the results of tests for uniformity of mix. This table shows the proportions of each ingredient that went into each batch sampled, the proportions of each ingredient found by analysis to be contained in each 30-pound sample of concrete removed from each batch, and the percentage variation in the proportion of each ingredient in each sample from the proportion of the corresponding ingredient in the batch as a whole. Variations above the actual batch proportion are shown as plus and variations below the actual batch proportion are shown as minus. The percentage variations shown in table 1 are summarized in table 2 which shows for all samples under each mixing time, the maximum individual plus and minus variations, the average plus and minus variations and the average of all variations regardless of sign. Figure 1 shows graphically the percentage variations in the proportions of materials as shown in table 1. Figure 2 shows the percentage variations computed for assumed samples each composed of the three samples taken from a batch.

Lack of uniformity in the distribution of the ingredients in each batch of concrete is shown by the data in the tables and diagrams. Had the mixing action resulted in a homogeneous mixture in which the materials were uniformly distributed throughout the batch, all samples would have contained materials in the same proportions as were used in charging the mixer. The results show that homogeniety did not exist in any batch of concrete tested. The summary in table 2 indicates that increasing the mixing time had no considerable effect in improving the uniformity of distribution of the ingredients. There is practically as great a lack of uniformity in the 4-minute concrete as there is in the 1-minute concrete.

Variations in the proportions of the ingredients in the different parts of the same batch were as high as 18 percent in some batches. Maximum spreads in the proportions in different parts of a group of batches for a given mixing time were from 10 to 24 percent. The spread between the average plus and average minus values for a given material ranged from 3 to 12 percent. The averages of all variations for a given material and mixing time and disregarding signs as shown in table 2 range from 1.6 to 5.7.

STRENGTH NOT IMPROVED BY INCREASING MIXING TIME FROM 1 TO 4 MINUTES

Table 3 gives the results of the strength tests. It shows the slump of the concrete in each sample, the compressive and flexural strength of individual specimens made from each sample, the average strength of all cylinders and beams made from each batch for each mixing time, and the percentage variation in the strength of every specimen from these averages. It shows the spread from the maximum individual to the minimum individual strength for both compression and flexure. Table 4 is a summary of the strength results, and shows the maximum and minimum individual strengths, the maximum spreads, and the average strengths of all specimens for each mixing time. Figures 3 and 4 show graphically the compressive and flexural strength, respectively, for the individual specimens made from each sample for each batch.

TABLE 1.—*Results of tests for uniformity of mix at plant 1*

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch										Sample designation	Proportions 30-pound sample by dry weight								Percentage variations in sample from proportions of original material			
		Cement		Fine aggregate		Coarse aggregate		Water					Cement		Fine aggregate		Coarse aggregate		Net water					
								Net		Absorbed														
		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Cement	Fine aggregate	Coarse aggregate	Net water
	Min.																							
6	1	3.78	12.6	9.65	32.1	13.87	46.3	2.49	8.3	0.21	0.7	A	3.56	11.9	9.79	32.6	14.08	47.0	2.35	7.8	−5.8	+1.5	+1.7	5.6
												B	3.96	13.2	9.52	31.8	13.89	46.3	2.41	8.0	+4.8	−1.3	+0.1	−3.2
												C	3.65	12.2	9.01	30.1	14.86	49.5	2.25	7.5	−3.4	−6.6	+7.1	−9
9	1	3.76	12.5	9.73	32.5	13.77	45.9	2.53	8.4	.21	.7	A	3.66	12.2	10.47	34.9	13.35	44.5	2.31	7.7	−2.7	+7.6	−3.0	8.7
												B	3.61	12.0	10.62	35.4	13.20	44.0	2.36	7.9	4.0	+9.1	−4.1	−6.7
												C	3.71	12.4	10.62	35.4	13.10	43.6	2.36	7.9	−1.3	+9.1	4.9	6.7
12	1	3.81	12.7	9.64	32.1	13.91	46.4	2.43	8.1	.21	.7	A	3.97	13.2	9.00	30.0	14.51	48.4	2.30	7.7	+4.2	−6.6	+4.5	−5.5
												B	3.71	12.4	9.31	31.0	14.43	48.1	2.33	7.8	−2.6	−3.4	+3.7	−4.1
												C	4.03	13.4	9.35	31.2	14.08	46.9	2.32	7.8	+5.8	−3.0	+1.2	4.5
16	1	3.75	12.5	9.80	32.7	13.72	45.7	2.52	8.4	.21	.7	A	4.45	14.8	9.53	31.8	13.30	44.3	2.51	8.4	+18.7	−2.8	−3.1	−0.4
												B	4.19	14.0	9.60	32.0	13.50	45.0	2.50	8.3	+11.7	−2.0	−1.6	0.8
												C	4.12	13.7	9.50	31.7	13.64	45.5	2.53	8.4	+9.9	−3.1	−0.6	+0.4
22	1	3.79	12.6	9.60	32.0	13.87	46.3	2.53	8.4	.21	.7	A	3.68	12.3	10.31	34.4	13.45	44.8	2.35	7.8	−2.9	+7.4	−3.0	−7.1
												B	3.80	12.7	10.46	34.9	13.11	43.7	2.42	8.1	+0.3	+9.0	−5.5	−4.3
												C	3.76	12.5	9.75	32.5	13.91	46.4	2.36	7.9	−0.8	0.1	+0.3	−6.6
1	2	3.77	12.6	9.70	32.3	13.77	45.9	2.54	8.5	.22	.7	A	3.47	11.6	9.34	31.1	14.42	48.1	2.55	8.5	−8.6	−3.7	+4.7	+0.4
												B	3.65	12.2	9.69	32.3	13.83	46.1	2.61	8.7	−3.2	−0.1	+0.4	+2.8
												C												
3	2	3.75	12.5	9.63	32.1	13.74	45.7	2.70	9.0	.21	.7	A	3.67	12.2	10.45	34.8	12.89	43.0	2.78	9.3	−2.1	+8.5	−6.0	−3.0
												B	3.51	11.7	10.12	33.8	13.42	44.7	2.74	9.1	−6.4	+5.1	−2.1	+1.5
												C	3.68	12.3	10.16	33.9	13.17	43.8	2.78	9.3	1.9	−5.5	−3.9	+3.0
11	2	3.76	12.5	9.67	32.3	13.77	45.9	2.59	8.6	.21	.7	A	3.99	13.3	9.51	31.7	13.74	45.8	2.54	8.5	+6.1	−1.7	0.2	−1.9
												B	3.85	12.8	9.21	30.7	14.18	47.3	2.54	8.5	+2.4	−4.8	+3.0	−1.9
												C	3.99	13.3	9.66	32.2	13.51	45.0	2.63	8.8	+6.1	−0.1	−1.9	+1.5
5	2	3.77	12.6	9.82	32.7	13.80	46.0	2.39	8.0	.22	.7	A	3.37	11.2	10.17	33.9	13.86	46.2	2.38	8.0	−10.6	+3.6	+0.4	−0.4
												B	3.36	11.2	10.24	34.2	13.81	46.0	2.37	7.9	−10.9	+4.3	+0.1	−0.8
												C	3.37	11.2	10.24	34.2	13.75	45.8	2.42	8.1	−10.6	+4.3	+0.4	+1.3
8	2	3.78	12.6	9.65	32.2	13.75	45.8	2.61	8.7	.21	.7	A	3.65	12.2	9.61	32.1	14.17	47.2	2.35	7.8	−3.4	−0.4	+3.1	−10.0
												B	3.85	12.8	10.04	33.5	13.42	44.7	2.48	8.3	+1.9	+4.0	−2.4	−5.0
												C	3.83	12.8	9.57	31.9	13.90	46.3	2.48	8.3	+1.3	−0.8	+1.1	5.0
	3	3.75	12.5	9.72	32.4	13.83	46.1	2.48	8.3	.22	.7	A	3.56	11.9	9.70	32.3	14.07	46.9	2.45	8.2	−5.1	−0.2	+1.7	−1.2
												B	3.90	13.0	10.49	35.0	12.74	42.4	2.67	8.9	+4.0	−7.9	−7.9	+7.7
												C	3.79	12.6	8.96	29.9	14.68	48.9	2.35	7.8	+1.1	−7.8	+6.1	−5.2
	3	3.82	12.7	9.86	32.9	13.82	46.1	2.29	7.6	.21	.7	A	3.78	12.6	9.83	32.7	13.85	46.2	2.32	7.7	−1.0	−0.3	+0.2	+1.3
												B	3.99	13.3	9.75	32.5	13.62	45.3	2.43	8.1	+4.5	−1.1	−1.4	+6.1
												C	3.52	11.7	9.24	30.8	14.78	49.3	2.23	7.4	−7.8	−6.3	+6.9	−2.6
0	3	3.79	12.6	9.63	32.1	13.89	46.3	2.48	8.3	.21	.7	A	4.01	13.3	9.18	30.6	14.18	47.3	2.41	8.0	+5.8	−4.7	+2.1	−2.8
												B	4.18	13.9	8.83	29.4	14.35	47.8	2.43	8.1	+10.3	−8.3	+3.3	2.0
												C	3.85	12.8	9.33	31.1	14.19	47.3	2.41	8.0	+1.6	−3.1	+2.2	−2.8
4	3	3.80	12.7	9.72	32.4	13.86	46.2	2.41	8.0	.21	.7	A	4.10	13.7	9.29	31.0	13.95	46.5	2.44	8.1	+7.9	−4.4	+0.6	+1.2
												B	4.12	13.7	9.37	31.2	13.96	46.5	2.33	7.9	+8.4	−3.6	+0.7	−3.3
												C	3.71	12.4	8.91	29.7	14.84	49.4	2.32	7.7	−2.4	8.3	+7.1	−3.7
9	3	3.75	12.5	9.79	32.7	13.69	45.6	2.56	8.5	.21	.7	A	3.62	12.1	9.85	32.8	13.91	46.3	2.40	8.0	−3.5	+0.6	+1.6	−5.9
												B	3.61	12.0	9.73	32.4	14.04	46.8	2.40	8.0	−3.7	−0.6	+2.6	−5.9
												C	3.59	12.0	9.65	32.2	14.13	47.1	2.41	8.0	−4.3	−1.4	+3.2	−5.9
8	3	3.78	12.6	9.69	32.3	13.86	46.2	2.46	8.2	.21	.7	A	3.41	11.4	10.33	34.4	13.63	45.3	2.42	8.2	−9.8	+6.6	−1.7	−1.6
												B	3.33	11.1	9.89	33.0	14.21	47.3	2.35	7.8	−11.9	+2.1	+2.5	−4.5
												C	3.46	11.5	9.86	32.9	14.15	47.2	2.31	7.7	−8.5	+1.8	+2.1	−6.1
	4	3.79	12.6	9.82	32.8	13.80	46.0	2.37	7.9	.22	.7	A	3.90	13.0	9.34	31.1	14.22	47.3	2.32	7.7	+2.9	−4.9	+3.0	−2.1
												B	3.87	12.9	9.59	32.0	14.00	46.7	2.32	7.7	+2.1	−2.3	+1.4	−2.1
												C	3.82	12.7	9.69	32.9	13.89	46.3	2.66	8.7	+0.8	−1.3	+0.7	+9.7
	4	3.77	12.6	9.57	31.9	13.74	45.8	2.71	9.0	.21	.7	A	3.77	12.6	9.66	32.2	13.80	46.0	2.55	8.5	0.0	+0.7	+0.1	5.9
												B	3.80	12.7	9.74	32.5	13.68	45.6	2.57	8.6	+0.8	+1.8	−0.4	−5.2
												C	3.87	12.9	9.60	32.0	13.70	45.7	2.62	8.7	+2.7	+0.3	−0.3	3.3
	4	3.73	12.4	9.68	32.3	13.67	45.6	2.71	9.0	.21	.7	A	3.54	11.8	10.39	34.6	13.21	44.0	2.65	8.8	5.1	+7.3	−3.4	−1.5
												B	3.45	11.5	10.15	33.8	13.60	45.3	2.59	8.6	−7.5	+4.9	−0.5	−4.4
												C	3.46	11.5	9.73	32.4	14.01	46.7	2.58	8.7	−7.2	+0.5	+2.5	−4.8
3	4	3.79	12.6	9.74	32.5	13.88	46.3	2.38	7.9	.21	.7	A	4.29	14.3	8.86	29.5	14.01	46.7	2.63	8.8	+13.2	−9.0	+0.9	+10.5
												B	4.31	14.4	8.77	29.2	14.09	47.0	2.62	8.7	+13.7	−10.0	+1.5	+10.1
												C	3.62	12.1	9.66	32.2	13.98	46.6	2.52	8.4	4.5	−0.8	+0.1	+5.9
	4	3.85	12.8	9.53	31.8	13.98	46.6	2.43	8.1	.21	.7	A	3.88	12.9	8.51	28.4	14.88	46.3	2.51	8.4	+0.8	−10.7	+6.1	+3.4
												B	3.94	13.1	8.86	29.5	14.39	48.0	2.60	8.7	+2.9	−7.0	+2.9	+7.0
												C	4.07	13.6	9.07	3.02	13.99	46.6	2.65	8.8	+5.7	1.8	+0.1	+9.0

In considering the strength results it should be emembered that different batches of concrete were sed for each mixing time, and that there was some ariation in the proportions of the ingredients in the ifferent batches as constant weights were used and o correction was made for moisture in the aggregates. ack of uniformity in the distribution of the ingredients ı the concrete, may have produced considerable varia-on in the proportions of the ingredients in the strength pecimens.

Since variations in batch proportions existed for all atches and since the uniformity results show no onsiderable difference in the lack of uniformity for any ixing time, study of the effect of the length of the ixing time on the strength of concrete will be based ı the spread in strengths and the average strength of all test specimens for each of the four mixing periods. Table 4 contains the data for this comparison. The average compressive strength of all specimens for the 1-minute mixing time is 3,590 pounds. The corresponding strength for the 4-minute mixing time is 3,738 pounds, an increase of 148 pounds or 4 percent. The significance of this small increase however is minimized by the fact that the spreads in strength from maximum to minimum for individual breaks, range from 1,220 to 1,700 pounds for the four mixing times, and by the fact that the average strength of the 2-minute concrete is less than that of the 1-minute concrete and the average strength of the 3-minute concrete is greater than that of the 4-minute concrete.

The average flexural strength for the 1-minute concrete is 518 pounds. The corresponding strength for

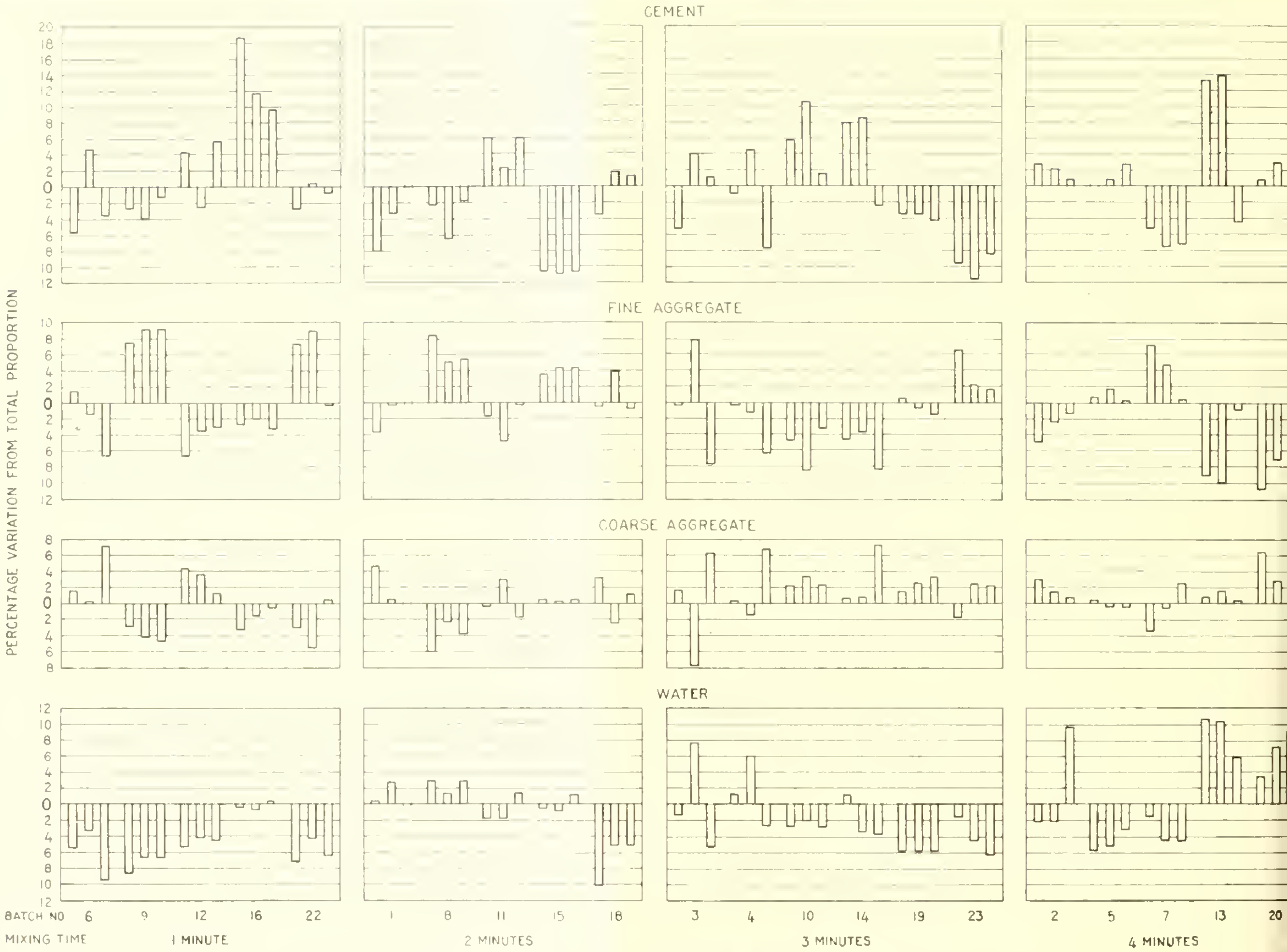


Figure 1.—Percentage Variations of Materials in Samples from Batch Proportions as Found in Tests at Plant
Samples from Each Batch Arranged in the Order A, B, C.

Table 2.—*Summary of variations of proportions of ingredients in samples from actual batch proportions in tests at plant 1*

Ingredient	Kind of variation	Mixing time in minutes			
		1	2	3	4
		Percent	*Percent*	*Percent*	*Percent*
Cement	Maximum individual plus	18.7	6.1	10.3	13.7
	Maximum individual minus	5.8	10.9	11.9	7.5
	Average plus	7.9	3.6	5.4	4.6
	Average minus	2.9	6.4	5.8	6.1
	Average plus and minus disregarding sign.	5.3	5.3	5.6	4.7
Sand	Maximum individual plus	9.1	8.5	7.9	7.3
	Maximum individual minus	6.6	4.8	8.3	10.7
	Average plus	7.3	5.0	3.8	2.6
	Average minus	3.2	1.7	3.9	5.6
	Average plus and minus disregarding sign.	4.8	3.3	3.8	4.4
Gravel	Maximum individual plus	7.1	4.7	7.1	6.4
	Maximum individual minus	5.5	6.0	7.9	3.4
	Average plus	2.6	1.8	2.9	1.8
	Average minus	3.2	2.4	3.7	1.2
	Average plus and minus disregarding sign.	2.9	2.1	3.0	1.6
Water	Maximum individual plus	.4	3.0	7.7	10.5
	Maximum individual minus	9.6	10.0	6.1	5.9
	Average plus	.4	1.9	4.1	8.0
	Average minus	5.3	3.6	3.8	3.7
	Average plus and minus disregarding sign.	4.9	2.7	3.9	5.7

the 4-minute concrete is 553 pounds, an increase of 35 pounds or 7 percent. The spread in strengths however is between 91 and 145 pounds for the four mixing times, and the average strength of the 2-minute concrete is greater than the strengths for the other mixing times. seems reasonable to conclude from these results that t length of the mixing time between 1 and 4 minutes, h no considerable effect on the strength of the concret

FINE AGGREGATE GROUND BY ACTION IN MIXER

At plant 1, grinding of the aggregate took pla during the mixing. The grinding of the coarse aggr gate to pass the no. 100 sieve was negligible. T grinding of the fine aggregate was appreciable a increased with the mixing time. Determination w made of the amount of sand passing the no. 100 sie in the material before mixing and also of sand grou up in mixing so that it passed the no. 100 sie Determinations were made for the 4 regular mixi periods and for extended mixing periods up to minutes. The results are shown in table 5.

This table shows that the length of the mixing ti had a marked effect on the gradation of the fine agg gate. The increase in the amount of fine aggreg passing the no. 100 sieve with increased mixing ti does not increase the strength of the concrete.

Designs of concrete mixtures are based in part the gradation of fine aggregate and, if this gradat is changed by grinding, the concrete produced will represent the design. Increasing the length of mixing time presents the possibility of producing ha ful effects on the gradation and on the resulting concr

FIGURE 2.—PERCENTAGE VARIATIONS OF MATERIALS FROM BATCH PROPORTIONS COMPUTED FOR ASSUMED SAMPLES COMPOSED OF THREE SAMPLES FROM A BATCH.

TABLE 3.—*Results of strength tests at plant 1*

Batch No.	Mixing time	Sample designation	Slump	Cylinders: Compressive strength	Cylinders: Percentage variation from average for batch	Beams: Flexural strength	Beams: Percentage variation from average for batch
	Minutes		*Inches*	*Pounds per square inch*		*Pounds per square inch*	
6	1	A	3¾	4,130 3,920	+6.4 +4.0	535	+1.9
		B	2½	3,990 3,850	+2.8 −0.8	480	−8.6
		C	3¼	3,540 3,850	−8.8 −0.8	561	+6.9
		Average		3,880		525	
		Maximum spread		590	15.2	81	15.5
9	1	A	1¾	3,130 3,210	−6.7 −4.3	507	+1.0
		B	3¼	3,470 3,550	+3.5 +5.9	549	+3.1
		C	4¾	3,510 3,250	+4.7 −3.1	480	−4.4
		Average		3,353		502	
		Maximum spread		420	12.6	39	7.8
12	1	A	2¼	3,850 3,690	−2.9 −6.9	531	+2.3
		B	3¼	3,950 3,900	−0.4 −1.6	518	−0.2
		C	2¾	4,320 4,080	+9.0 +2.9	509	−2.0
		Average		3,965		519	
		Maximum spread		630	15.9	22	4.3
16	1	A	6½	3,150 3,080	−3.1 −5.2	557	+9.9
		B	6½	3,310 3,510	−1.8 +8.0	491	2.6
		C	6¾	3,470 2,980	+6.8 −8.3	470	−7.3
		Average		3,250		507	
		Maximum spread		530	16.3	87	17.2
22	1	A	3½	3,490 3,500	−0.3 −0.1	556	+3.7
		B	3¾	3,420 3,560	−2.3 +1.7	522	2.6
		C	3	3,410 3,630	−2.6 +3.6	530	−1.1
		Average		3,502		536	
		Maximum spread		220	6.2	34	6.3
1	2	A	2¼	3,800 3,960	−2.2 +1.9	582	+4.2
		B	2	4,060 3,850	+4.5 −0.9	536	−4.1
		C	2	3,850 3,790	−0.9 +2.4	558	−0.2
		Average		3,885		559	
		Maximum spread		270	6.9	46	8.3
8	2	A	4	2,770 3,020	−1.8 +7.0	560	−1.9
		B	5	2,730 2,810	−3.3 −0.4	511	[illegible]
		C	6¼	2,920 2,680	+3.5 −5.0	612	+7.2
		Average		2,822		571	
		Maximum spread		340	12.0	71	12.5
11	2	A	5	3,630 3,620	−2.7 −3.0	518	−0.8
		B	5¾	3,670 3,920	−1.6 +5.0	480	−8.1
		C	5¾	3,770 3,780	+1.0 +1.3	569	+9.0
		Average		3,732		522	
		Maximum spread		300	8.0	89	17.1
15	2	A	5½	3,330 3,270	+3.0 +1.2	606	+0.2
		B	5¾	3,360 3,450	+3.9 2.6	590	−2.5
		C	5½	3,090 3,190	−4.4 −1.3	649	+2.3
		Average		3,233		605	
		Maximum spread		270	8.3	29	4.8
18	2	A	5½	3,990 4,140	−5.2 −1.7	608	+2.4
		B	6	4,300 4,280	+2.4 +1.7	584	−1.7
		C	3¼	4,380 4,480	4.0 −0.7	589	0.8
		Average		4,224		591	
		Maximum spread		390	9.2	24	4.1
3	3	A	4¾	3,810 3,480	+4.4 4.3	562	+1.6
		B	7	3,710 3,860	+1.7 +5.8	593	+3.5
		C	5¼	3,480 3,540	−4.6 3.0	543	−5.2
		Average		3,648		573	
		Maximum spread		380	10.4	50	8.7
4	3	A	3½	4,250 4,200	+2.1 +0.9	540	+0.9
		B	5	4,230 4,050	+1.6 −2.7	535	0.0
		C	2½	4,180 4,070	+0.4 2.2	529	−0.7
		Average		4,163		535	
		Maximum spread		200	4.8	11	1.6
10	3	A	6½	3,980 3,870	−0.7 −3.4	603	+9.0
		B	6	4,060 3,980	+1.3 −0.7	471	14.5
		C	7½	4,080 4,070	+1.8 +1.6	582	−5.3
		Average		4,007		553	
		Maximum spread		210	5.2	129	23.[illegible]
11	3	A	5¾	4,070 4,150	4.0 −2.1	552	−5.8
		B	6	4,320 4,260	+1.9 +0.5	619	+7.8
		C	5¾	4,410 4,490	3.1 +5.9	585	0.0
		Average		4,240		585	
		Maximum spread		420	9.9	67	11.6

TABLE 3.—*Results of strength tests at plant 1*—Continued

Batch No.	Mixing time	Sample designation	Slump	Cylinders: Compressive strength	Cylinders: Percentage variation from average for batch	Beams: Flexural strength	Beams: Percentage variation from average for batch
	Minutes		*Inches*	*Pounds per square inch*		*Pounds per square inch*	
19	3	A	5½	4,080 4,160	−3.4 −1.5	606	+3.1
		B	5¾	4,400 4,360	+4.2 +3.2	612	+4.1
		C	6	4,340 4,000	+2.8 −5.3	545	−7.3
		Average		4,223		588	
		Maximum spread		400	9.5	67	11.4
23	3	A	3¼	3,390 3,430	−2.2 −1.1	535	+3.9
		B	3¾	3,690 3,550	+6.7 +2.4	492	−4.5
		C	5	3,270 3,470	−5.7 +0.1	518	+0.6
		Average		3,467		515	
		Maximum spread		420	12.4	43	8.4
2	4	A	5½	4,030 4,040	−2.5 −2.3	592	−1.0
		B	5	4,030 4,260	−2.5 +3.0	608	+1.7
		C	4¼	4,250 4,200	+2.8 +1.6	595	−0.5
		Average		4,135		598	
		Maximum spread		230	5.5	16	2.7
5	4	A	4¾	3,610 3,530	−4.5 −6.6	541	−0.7
		B	5½	3,730 4,060	−1.3 +7.4	535	−1.8
		C	4	3,820 3,910	+1.0 +4.2	558	+2.4
		Average		3,781		545	
		Maximum spread		530	14.0	23	4.2
7	4	A	3¾	3,130 3,040	−1.8 −4.6	546	+4.8
		B	4¾	3,090 3,140	−3.0 −1.5	507	−2.7
		C	5	3,410 3,310	+7.1 +3.6	511	−1.9
		Average		3,187		521	
		Maximum spread		370	11.7	39	7.5
13	4	A	5½	4,130 4,100	−2.1 −2.8	600	+2.0
		B	5¾	4,360 4,090	+3.4 −3.0	585	−0.5
		C	5½	4,290 4,340	+1.7 +2.9	579	−1.5
		Average		4,218		588	
		Maximum spread		270	6.4	21	3.5
20	4	A	5¾	3,440 3,560	+2.1 +5.7		
		B	6¼	3,160 3,360	−6.2 −0.2	495	+1.4
		C	6¼	3,300 3,390	−2.0 +0.7	481	−1.4
		Average		3,368		488	
		Maximum spread		400	11.9	14	2.8

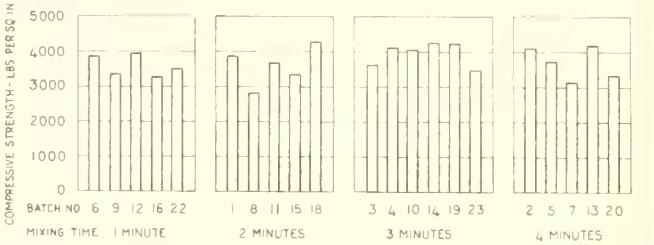


FIGURE 3.—COMPRESSIVE STRENGTHS AVERAGED BY BATCHES FOR ALL BATCHES AT PLANT 1.

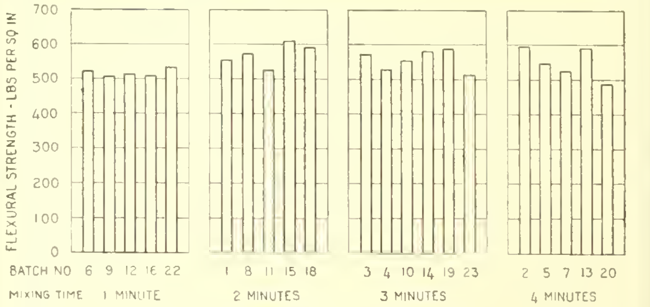


FIGURE 4.—FLEXURAL STRENGTHS AVERAGED BY BATCHES FOR ALL BATCHES AT PLANT 1.

TABLE 4.—*Summary of strength test results at plant 1*

COMPRESSIVE STRENGTH

Mixing time	Maximum individual	Minimum individual	Maximum spread	Average strength
Minutes	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	4,320	2,980	1,340	3,590
2	4,380	2,680	1,700	3,576
3	4,490	3,270	1,220	3,957
4	4,360	3,040	1,320	3,738

FLEXURAL STRENGTH

Mixing time	Maximum individual	Minimum individual	Maximum spread	Average strength
1	561	470	91	518
2	619	480	139	570
3	619	474	145	558
4	608	481	127	553

TABLE 5.—*Percentage of sand passing the no. 100 sieve*

Mixing time in minutes:	*Percentage of sand passing*
0	4.0
1	6.0
2	7.5
3	9.0
4	10.5
18	14.0
37	16.0
45	18.5
70	23.0

STUDIES MADE AT A SECOND PLANT

A series of studies were made at a second plant using a stationary no. 126–S mixer. The drum was 108 inches in diameter, 90 inches in length and was revolved 11 times per minute.

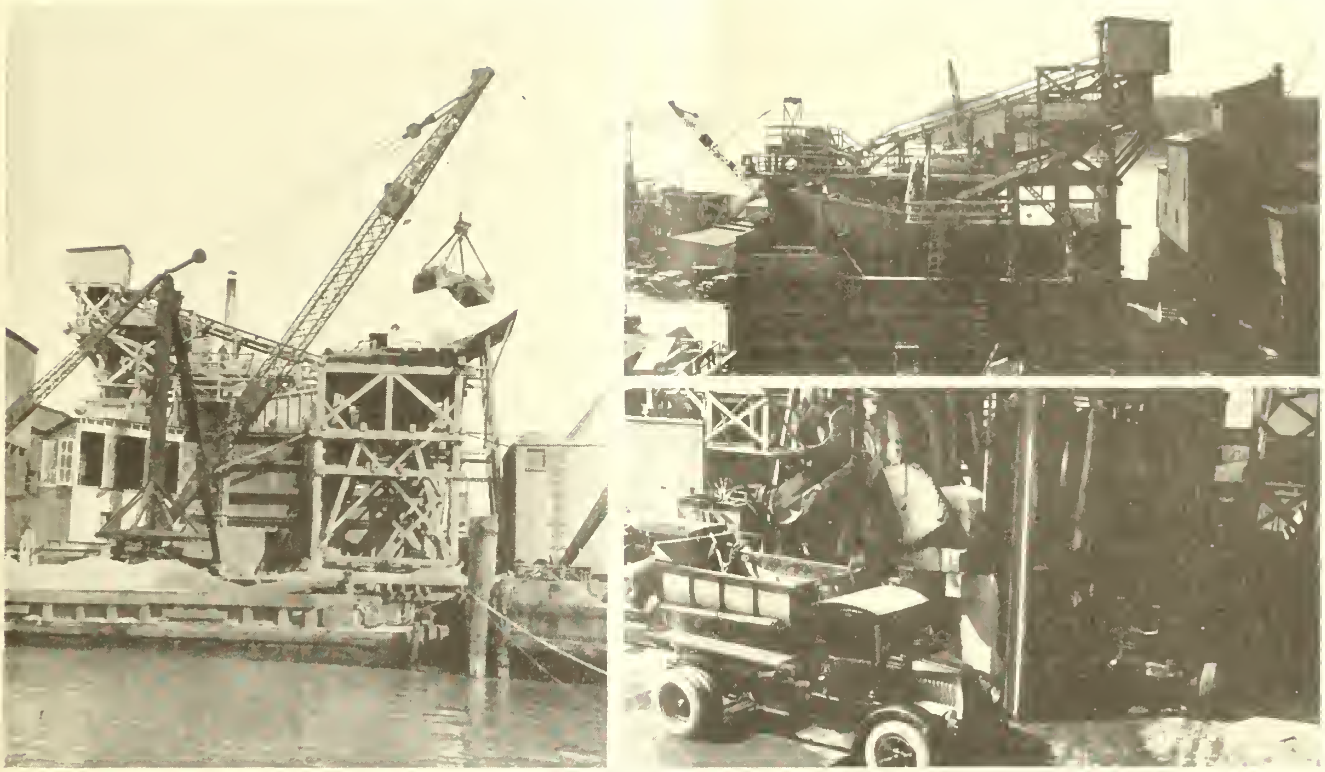
The proportions by dry weight of the average batch were as follows:

	Pounds
Cement	2,363
Fine aggregate	6,789
Coarse aggregate	9,465
Net water	1,866
Absorbed water	62

These quantities produced a batch with an absolute volume of 140 cubic feet.

The sand used as fine aggregate was analyzed as follows:

	Percentage retained
Sieve no. 4	7
Sieve no. 8	19
Sieve no. 14	33
Sieve no. 28	57
Sieve no. 48	90
Sieve no. 100	99



Equipment at Plant No. 1.

Gravel was used as coarse aggregate. Two different sizes were used, one having a maximum size of 1¼ inches and the other a maximum size of three-fourths inch. These gravels were used, each in different series of tests. Their gradations were as follows:

Screen opening	Maximum size ¾ inch, percentage retained	Maximum size 1¼ inches, percentage retained
1½ inches	0	0
¾-inch	16	65
⅜-inch	72	90
No. 4	98	98

In general the procedure followed at plant 2 was different from that followed at plant 1. One set of batches was used for the uniformity tests and another set of batches was used for the strength tests. Both the strength and uniformity tests were divided into two series, one in which the maximum size of coarse aggregate was 1¼ inches, and one in which the maximum size of coarse aggregate was three-fourths inch. The mixing periods were 1, 2, 3, and 4 minutes.

TESTS AT PLANT 2 SHOW LACK OF UNIFORMITY FOR ALL MIXING TIMES

In the uniformity tests a different batch of concrete was used for each mixing period. After a batch had been mixed for a given time it was discharged from the mixer and samples were taken by intercepting the flow. Five 30-pound samples were taken, the first at the beginning of the discharge, the last near the end of the discharge and the three intermediate samples were obtained at uniform intervals of time during the discharge. The samples were analyzed and the proportions determined and compared with the proportions of the batch before mixing in the same manner as in the tests at plant 1. Three batches with ¾-inch coarse aggregate and three with 1¼-inch coarse aggregate for each of the four mixing periods were analyzed. This involved the analysis of fifteen 30-pound samples for each mixing period for each size of coarse aggregate.

The results of the tests for uniformity of mix are shown in table 6. The data in this table correspond with that in table 1 for the uniformity studies at plant 1. Table 7 summarizes the percentage variations contained in table 6, and corresponds with the data in table 2 for plant 1. Figures 5 and 6 show graphically the percentage variations in the proportions of cement, fine aggregate, coarse aggregate and water in each sample removed from each batch from the proportions of the corresponding ingredients in the batch from which the samples were removed. Figure 7 shows the percentage variations computed for assumed samples, each composed of the five samples taken from a batch.

The tables and figures mentioned above show a consistent lack of uniformity in the samples taken at plant 2. Variations in the proportions of the ingredients in different parts of the same batch were higher than 20 percent in some batches. Maximum spreads in the proportions in different parts of a group of batches for a given mixing time were from 8 to 40 percent. The spread between the average plus and the average minus values for a given material ranged from 4 to 18 percent. The average variation in the proportion of each ingredient from the actual batch proportion was between 2.1 and 8.8 percent, as shown in table 7. An analysis of these data indicates that the length of the mixing time had no considerable effect on the uniformity of distribution of the ingredients.

TESTS AT PLANT 2 SHOW NO APPRECIABLE GAIN IN STRENGTH WITH INCREASE IN MIXING TIME

Samples for strength tests were obtained from a given batch after 1, 2, 3, and 4 minutes of mixing by inserting

TABLE 6.—*Results of tests for uniformity of mix at plant 2*

CONCRETE WITH ¾-INCH COARSE AGGREGATE

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch										Sample designation	Proportions of 30-pound sample by dry weight								Percentage variations in sample from proportions of original material			
		Cement		Fine aggregate		Coarse aggregate		Water					Cement		Fine aggregate		Coarse aggregate		Net water					
								Net		Absorbed														
		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Cement	Fine aggregate	Coarse aggregate	Net water
	Minutes																							
6-U	1	3.39	11.3	10.39	34.6	13.15	44.9	2.68	8.9	.09	0.3	A	3.53	11.8	9.33	31.1	14.63	48.8	2.42	8.1	+4.1	−10.2	+8.8	−9.7
												B	3.33	11.1	10.19	34.0	13.87	46.2	2.52	8.4	−1.8	−1.9	+3.1	−5.2
												C	3.33	11.1	10.35	34.5	13.63	45.4	2.60	8.7	−1.8	−0.4	+1.3	−3.0
												D	3.42	11.4	10.75	35.8	13.03	43.4	2.71	9.0	+0.9	+3.5	−3.1	+1.1
												E	3.43	11.4	10.22	34.1	13.63	54.4	2.63	8.8	+1.2	−1.6	+1.3	−1.9
7-U	1	3.38	11.3	10.40	34.7	13.39	44.6	2.71	9.1	.09	.3	A	3.80	12.7	10.11	33.7	13.25	44.2	2.75	9.2	+12.4	−2.8	−1.0	+0.4
												B	3.58	11.9	9.69	32.3	14.00	46.7	2.64	8.8	+5.9	−6.8	+4.6	−3.6
												C	3.61	12.0	10.04	33.5	13.48	44.9	2.78	9.3	+6.8	−3.5	+0.7	+1.5
												D	3.55	11.8	10.14	33.8	13.34	44.5	2.88	9.6	+5.0	−2.5	−0.4	+5.1
												E	3.68	12.3	9.70	32.3	13.78	45.9	2.75	9.2	+8.9	−6.7	+2.9	+0.4
10-U	1	3.46	11.5	10.43	34.8	13.30	44.3	2.72	9.1	.09	.3	A	3.77	12.6	10.09	33.6	13.44	44.8	2.61	8.7	+9.0	−3.3	+1.1	−4.0
												B	3.24	10.8	10.26	34.2	13.71	45.7	2.70	9.0	−6.4	−1.6	+3.1	−0.7
												C	3.40	11.3	10.49	35.0	13.30	44.3	2.72	9.1	−1.7	+0.6	0.0	0.0
												D	3.38	11.3	10.24	34.1	13.67	45.6	2.62	8.7	−2.3	−1.8	+2.8	−3.7
												E	3.30	11.0	8.98	29.9	15.17	50.6	2.45	8.2	−4.6	−13.9	+14.1	−9.9
1-U	2	3.39	11.3	10.33	34.4	13.29	44.3	2.90	9.7	.09	.3	A	3.39	11.3	10.87	36.2	12.77	42.6	2.88	9.6	0.0	+5.2	−3.9	−0.7
												B	3.13	10.4	10.65	35.5	13.14	44.8	2.69	9.0	−7.7	+3.1	+1.1	−7.2
												C	3.32	11.1	10.83	36.1	12.93	43.1	2.83	9.4	−2.1	+4.8	−2.7	−2.4
												D	3.32	11.1	10.72	35.7	13.16	43.9	2.71	9.0	−2.1	+3.8	−0.9	−6.6
												E	3.36	11.2	10.78	35.9	12.93	13.1	2.84	9.5	−0.9	+4.4	−2.7	−2.1
2-U	2	3.39	11.3	10.21	34.1	13.45	44.8	2.86	9.5	.09	.3	A	3.49	11.6	9.72	32.4	14.04	46.8	2.66	8.9	+2.9	−4.8	+4.4	−7.0
												B	3.23	10.8	9.87	32.9	14.13	47.1	2.68	8.9	−4.7	−3.3	+5.1	−6.3
												C	3.30	11.0	9.97	33.2	13.91	46.4	2.73	9.1	+2.7	−2.3	+3.4	−4.5
												D	3.30	11.0	10.55	35.2	13.24	44.1	2.82	9.4	+2.7	+3.3	−1.6	−1.4
												E	3.55	11.8	10.35	34.5	13.14	43.8	2.87	9.6	+4.7	+1.4	−2.3	+0.3
[illegible]	2	3.35	11.2	10.40	34.7	13.38	44.5	2.78	9.3	.09	.3	A	4.03	13.4	10.62	35.4	12.61	42.1	2.65	8.8	+20.3	+2.1	−5.7	−4.7
												B	3.65	12.2	10.63	35.4	12.93	43.1	2.70	9.0	+9.0	+2.2	−3.4	−2.9
												C	3.66	12.2	10.43	34.8	13.11	43.7	2.71	9.0	+9.3	+0.3	−2.0	−2.5
												D	3.55	11.8	10.73	35.8	12.84	42.8	2.79	9.3	+6.0	+3.2	−4.0	+0.4
												E	3.52	11.7	9.54	31.8	14.31	47.7	2.64	8.5	+5.1	−8.3	+6.9	−8.6
[illegible]	3	3.41	11.4	10.35	34.5	13.27	44.2	2.88	9.6	.09	.3	A	3.64	12.1	9.82	32.8	13.75	45.8	2.70	9.0	+6.7	−5.1	+3.6	−6.2
												B	3.36	11.2	10.18	33.9	13.56	45.2	2.81	9.4	−1.5	−1.6	+2.2	−2.4
												C	3.51	11.7	10.12	33.7	13.45	44.9	2.83	9.4	+2.9	−2.2	+1.4	−1.7
												D	3.55	11.8	10.22	34.1	13.23	44.1	2.91	9.7	+4.1	−1.3	−0.1	+1.0
												E	3.48	11.6	10.08	33.6	13.52	45.1	2.83	9.4	+2.0	−2.6	+1.9	−1.7
4-U	3	3.40	11.3	10.36	34.5	13.52	45.1	2.63	8.8	.09	.3	A	3.52	11.7	9.70	32.3	14.15	47.2	2.54	8.5	+3.5	−6.4	+4.7	−3.4
												B	3.48	11.6	9.78	32.6	13.98	46.6	2.67	8.9	+2.3	−5.6	+3.4	+1.5
												C	3.51	11.7	9.72	32.4	14.00	46.7	2.68	8.9	+3.1	−6.2	+3.5	+1.9
												D	3.42	11.4	9.50	31.7	14.35	47.8	2.64	8.8	+0.6	−8.3	+6.1	+1.4
												E	3.27	10.9	9.07	30.3	15.06	50.2	2.50	8.3	−3.8	−12.4	+11.4	−4.9
11-U	3	3.40	11.3	10.39	34.6	13.42	44.8	2.70	9.0	.09	.3	A	4.12	13.7	9.30	31.0	13.97	46.6	2.52	8.4	+21.1	−10.5	+4.1	−6.7
												B	3.33	11.1	10.03	33.4	13.90	46.1	2.65	8.8	−2.1	−3.5	+3.6	−1.9
												C	3.21	10.7	10.12	33.7	13.92	46.4	2.66	8.9	−5.6	−2.6	+3.7	−1.5
												D	3.35	11.2	10.17	33.9	13.67	45.5	2.72	9.1	−1.5	−2.1	+1.9	+0.7
												E	3.24	10.8	9.83	32.8	14.23	47.4	2.61	8.7	−4.7	−5.4	+6.0	−3.3
8-U	4	3.41	11.4	10.40	34.7	13.30	44.3	2.80	9.3	.09	.3	A	3.38	11.3	10.36	34.5	13.51	45.0	2.66	8.9	−0.9	−0.4	+1.6	−5.0
												B	3.27	10.9	10.51	35.0	13.36	44.0	2.77	9.2	−4.1	+1.1	+0.5	−1.1
												C	3.32	11.1	10.35	34.5	13.51	45.0	2.73	9.1	−2.6	−0.5	+1.6	−2.5
												D	3.35	11.2	10.36	34.5	13.44	44.8	2.76	9.2	−1.8	−0.4	+1.1	−1.4
												E	2.98	9.9	10.11	33.8	14.26	47.5	2.56	8.5	−12.6	−2.8	+7.2	−8.6
12-U	4	3.42	11.4	10.36	34.5	13.36	44.6	2.77	9.2	.09	.3	A	3.89	13.0	10.53	35.1	12.74	42.4	2.75	9.2	+13.7	+1.6	−4.6	−0.7
												B	3.71	12.4	10.59	35.3	12.84	42.8	2.77	9.2	+8.5	+2.2	−3.9	0.0
												C	3.77	12.6	10.15	33.8	13.20	44.0	2.79	9.3	+10.2	−2.0	−1.2	+0.7
												D	3.65	12.2	10.43	34.8	13.06	43.5	2.77	9.2	+6.7	+0.7	−2.2	0.0
												E	3.67	12.2	9.77	32.6	13.77	45.9	2.70	9.6	+7.3	−5.7	+3.1	−2.5
13-U	4	3.39	11.3	10.33	34.4	13.35	44.5	2.84	9.5	.09	.3	A	3.86	12.9	10.44	34.8	12.83	42.7	2.78	9.3	+13.9	+1.1	−3.9	−2.1
												B	3.59	12.0	10.02	33.4	13.53	45.1	2.77	9.2	+5.9	−3.0	+1.3	−2.5
												C	3.42	11.4	10.34	34.5	13.26	44.2	2.89	9.6	+0.9	+0.1	−0.7	+1.8
												D	3.47	11.6	9.83	32.8	14.04	46.8	2.57	8.6	+2.5	−4.8	+5.2	−9.5
												E	3.62	12.1	9.85	32.8	13.61	45.4	2.83	9.4	+6.8	−4.6	+1.9	−0.4
CONCRETE WITH 1¼-INCH COARSE AGGREGATE																								
5-U	1	3.42	11.4	9.48	31.6	14.64	48.8	2.38	7.9	.08	.3	A	3.36	11.2	8.83	29.4	15.51	51.7	2.21	7.4	−1.8	−6.9	+5.9	−7.1
												B	3.20	11.7	8.83	29.4	15.68	52.3	2.20	7.3	−6.4	−6.9	+7.1	−7.6
												C	3.36	11.2	9.71	32.4	14.43	48.1	2.41	8.0	−1.8	+2.4	−1.4	+1.3
												D	3.11	10.4	9.07	30.3	15.49	51.6	2.23	7.4	−9.1	−4.3	+5.8	−6.3
												E	3.17	10.6	8.83	29.4	15.55	51.8	2.36	7.9	−7.3	−6.9	+6.2	−.8
[illegible]	1	3.40	11.3	9.52	31.8	14.20	47.3	2.79	9.3	.09	.3	A	4.32	14.4	8.51	28.4	14.57	48.5	2.52	8.4	+27.1	−10.6	+2.6	−9.7
												B	3.37	11.2	9.06	30.2	14.85	49.5	2.63	8.8	−.9	−4.8	+4.6	−5.7
												C	3.58	11.9	8.76	29.2	14.91	49.7	2.67	8.9	+5.3	−8.0	+5.0	−4.3
												D	3.57	11.9	9.33	31.1	14.32	47.7	2.69	9.0	+5.0	−2.0	+.8	−3.6
												E	3.67	12.2	9.02	30.1	14.50	48.3	2.72	9.1	+7.9	−5.3	+2.1	−2.5
16-U	1	3.40	11.3	9.61	32.1	14.19	47.3	2.71	9.0	.09	.3	A	4.48	14.9	9.81	32.7	12.86	42.9	2.76	9.2	+31.7	+2.1	−9.4	+1.8
												B	3.19	10.6	9.05	30.2	15.17	50.6	2.49	8.3	−6.2	−5.8	+6.9	−8.1
												C	3.51	11.7	9.66	32.2	14.08	46.9	2.66	8.9	+3.2	+.5	−.8	−1.8
												D	3.28	10.9	9.30	31.0	14.68	49.0	2.65	8.8	−3.5	−3.2	+3.5	−2.2
												E	3.19	10.6	8.64	28.8	15.59	52.0	2.49	8.3	−6.2	−10.1	+9.9	−8.1
21-U	2	3.38	11.3	9.58	31.9	14.20	47.3	2.75	9.2	.09	.3	A	3.24	10.8	9.07	30.2	14.91	49.7	2.69	9.0	−4.7	−5.3	+5.0	−2.2
												B	3.11	10.4	8.65	28.8	15.63	52.1	2.52	8.4	−8.0	−9.7	+10.1	−8.4
												C	3.10	10.3	8.88	29.6	15.27	50.9	2.66	8.9	−8.3	−7.3	+7.5	−3.3
												D	3.30	11.0	9.27	30.9	14.57	48.6	2.77	9.2	−2.4	−3.2	+2.6	+.7
												E	3.53	11.8	9.74	32.5	13.73	45.7	2.91	9.7	+4.4	+1.7	−3.3	+5.8
[illegible]	2	3.40	11.3	9.56	31.9	14.24	47.5	2.71	9.0	.09	.3	A	3.21	10.7	8.50	28.3	15.60	52.0	2.60	8.7	−5.6	−11.1	+9.6	−4.1
												B	3.29	11.0	9.22	30.7	14.69	49.0	2.71	9.0	−3.1	−3.6	+3.2	.0
												C	3.24	10.8	8.92	29.7	15.05	50.2	2.70	9.0	−4.7	−6.7	+5.7	−.4
												D	3.36	11.2	9.14	30.5	14.64	48.8	2.77	9.2	−1.2	−4.4	+2.8	+2.2
												E	3.27	10.9	9.22	30.7	14.67	48.9	2.75	9.2	−3.8	−3.6	+3.0	+1.5

TABLE 6.—*Results of tests for uniformity of mix at plant 2*—Continued

CONCRETE WITH 1¼-INCH COARSE AGGREGATE—Continued

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch										Sample designation	Proportions of 30-pound sample by dry weight								Percentage variations in sample from proportions of original material			
		Cement		Fine aggregate		Coarse aggregate		Water					Cement		Fine aggregate		Coarse aggregate		Net water					
								Net		Absorbed														
		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent		Weight in pounds	Percent	Weight in pounds	Percent	Weigh in pounds	Percent	Weight in pounds	Percent	Cement	Fine aggregate	Coarse aggregate	Net water
24-U	*Min.* 2	3.38	11.3	9.54	31.8	14.06	46.8	2.93	9.8	.09	.3	A	3.46	11.5	9.58	31.9	14.14	47.2	2.73	9.1	+2.4	+.4	+.6	−6.8
												B	3.76	12.5	10.29	34.3	12.98	43.3	2.88	9.6	+11.2	+7.9	−7.7	−1.7
												C	3.55	11.8	10.35	34.5	13.16	43.9	2.85	9.5	+5.0	+8.5	6.4	2.7
												D	3.61	12.0	10.39	34.6	13.04	43.5	2.87	9.6	+6.8	+8.9	−7.3	−2.0
												E	3.77	12.6	10.26	34.2	12.99	43.3	2.89	9.6	+9.2	+7.5	−7.6	−1.4
14-U	3	3.39	11.3	9.59	32.0	14.03	46.7	2.90	9.7	.09	.3	A	4.01	13.4	9.16	30.5	13.83	46.1	2.91	9.7	+18.3	−4.5	1.4	.3
												B	3.31	11.0	9.08	30.3	14.80	49.3	2.72	9.1	2.4	−5.3	+5.5	−6.2
												C	3.73	12.4	9.00	30.0	14.41	48.1	2.77	9.2	+10.6	−6.1	+2.8	4.5
												D	3.76	12.5	9.24	30.8	14.09	47.0	2.82	9.4	+10.9	3.6	+.4	−2.8
												E	3.71	12.4	8.94	29.8	14.47	48.2	2.80	9.3	+9.4	−6.8	+3.1	−3.1
17-U	3	3.39	11.3	9.70	32.3	14.18	47.3	2.64	8.8	.09	.3	A	4.67	15.6	9.13	30.4	13.39	44.6	2.72	9.1	+37.7	5.9	−5.6	+3.0
												B	3.20	10.7	9.27	30.9	14.76	49.2	2.68	8.9	−5.6	−4.1	+4.1	+1.5
												C	3.33	11.1	9.74	32.5	14.11	47.0	2.74	9.1	−2.1	+.1	−.5	+3.8
												D	3.42	11.4	9.74	32.5	14.03	46.7	2.72	9.1	+.9	+.4	−1.1	+3.0
												E	3.49	11.6	9.16	30.5	14.50	48.3	2.76	9.2	+2.9	−5.6	+2.3	+4.5
18-U	3	3.74	12.5	10.76	35.8	12.51	41.7	2.90	9.7	.09	.3	A	3.68	12.3	10.75	35.8	12.66	42.2	2.82	9.4	−4.3	.1	+1.2	−2.8
												B	3.64	12.1	11.23	37.4	12.16	40.0	2.87	9.6	−5.3	+4.4	−2.8	−1.0
												C	3.64	12.1	11.25	37.5	12.10	40.4	2.91	9.7	−5.3	+4.6	3.3	+.3
												D	3.36	11.2	11.25	37.5	12.43	41.5	2.86	9.5	−10.2	+4.6	−.6	−1.4
												E	3.51	11.7	10.75	35.8	12.83	42.8	2.82	9.4	−6.1	.1	+2.6	−2.8
19-U	4	3.72	12.4	8.75	29.2	15.01	50.0	2.42	8.1	.10	.3	A	3.70	12.3	7.94	26.5	15.90	53.0	2.37	7.9	−.8	−9.4	+5.9	−2.1
												B	3.63	12.1	8.54	28.5	15.37	51.2	2.37	7.9	−2.1	2.4	+2.4	2.1
												C	3.82	12.7	8.77	29.2	14.76	49.2	2.57	8.6	+2.4	+.2	−1.7	+6.2
												D	3.90	13.0	9.30	31.0	14.14	47.1	2.57	8.6	+4.6	+6.3	−5.8	+6.2
												E	3.87	12.9	9.10	30.3	14.36	47.9	2.58	8.6	+3.8	+4.0	−4.3	+6.6
20-U	4	3.73	12.4	8.84	29.5	14.91	49.7	2.43	8.1	.09	.3	A	3.87	12.9	8.90	29.6	14.51	48.4	2.64	8.8	+3.8	+.7	−2.7	+8.6
												B	3.52	11.7	8.78	29.3	14.98	49.9	2.63	8.8	−5.6	−.7	+.5	+8.2
												C	3.58	11.9	8.74	29.1	15.04	50.2	2.55	8.5	−4.0	−1.1	+.9	+4.9
												D	3.74	12.5	8.90	29.6	14.65	48.8	2.63	8.8	+.3	+.7	−1.7	+8.2
												E	3.90	13.0	9.37	31.2	13.90	46.4	2.74	9.1	+4.6	+6.0	−6.8	+12.7
23-U	4	3.74	12.5	8.65	28.8	14.99	50.0	2.53	8.4	.09	.3	A	3.78	12.6	8.36	27.9	15.27	50.9	2.50	8.3	+1.1	−3.4	+1.9	−1.2
												B	3.83	12.8	8.68	28.9	14.83	49.4	2.58	8.6	+2.4	+.3	−1.1	+2.0
												C	3.84	12.8	8.68	28.9	14.81	48.4	2.59	8.6	+2.7	+.3	−1.2	+2.4
												D	3.96	13.2	8.99	30.0	14.36	47.8	2.60	8.7	+5.9	+3.9	−4.2	+2.8
												E	3.71	12.4	8.06	26.9	15.62	52.0	2.52	8.4	−.8	−6.8	+4.2	+.4

TABLE 7.—*Summary of variations of proportions of ingredients in samples from actual batch proportions in tests at plant 2*

Ingredients	Kind of variation	¾-inch gravel				1¼-inch gravel			
		Mixing time in minutes							
		1	2	3	4	1	2	3	4
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cement	Maximum individual plus	12.4	20.3	21.1	13.9	31.7	11.2	37.7	5.9
	Maximum individual minus	6.4	7.7	5.6	12.6	9.1	8.3	10.2	5.6
	Average plus	6.0	7.0	5.1	7.6	13.4	6.5	13.0	3.2
	Average minus	3.1	3.5	3.2	4.4	4.8	4.6	5.2	2.7
	Average plus and minus, disregarding sign.	4.9	5.3	4.4	6.6	8.2	5.4	8.8	3.0
Sand	Maximum individual plus	3.5	5.2	----	2.2	2.4	8.9	4.6	6.3
	Maximum individual minus	13.9	8.3	12.4	5.7	10.6	11.1	6.8	9.4
	Average plus	2.0	3.1	----	1.1	1.7	5.8	2.8	2.5
	Average minus	4.4	4.7	5.1	2.7	6.2	6.1	4.2	4.0
	Average plus and minus, disregarding sign.	4.1	3.5	5.1	2.1	5.3	6.0	3.7	3.1
Gravel	Maximum individual plus	14.1	6.9	11.4	7.2	9.9	10.1	5.5	5.9
	Maximum individual minus	3.1	5.7	.1	4.6	9.4	7.7	5.6	6.8
	Average plus	4.0	4.2	4.1	2.6	5.0	5.0	2.8	2.6
	Average minus	1.5	2.9	.1	2.8	3.9	6.5	2.2	3.3
	Average plus and minus, disregarding sign.	3.2	3.3	3.8	2.7	4.8	5.5	2.5	3.0
Water	Maximum individual plus	5.1	.4	1.9	1.8	1.8	5.8	4.7	12.7
	Maximum individual minus	9.9	8.6	6.7	9.5	9.7	8.4	6.2	2.1
	Average plus	1.7	.3	1.3	1.2	1.6	2.6	2.7	.8
	Average minus	4.6	4.4	3.4	3.3	5.2	3.3	2.8	[illegible]
	Average plus and minus, disregarding sign.	3.3	3.8	2.7	2.6	4.7	2.9	2.8	[illegible]

an auxiliary chute into the drum at the end of each of these mixing periods. A sample weighed approximately 150 pounds and was used to make two 6- by 12-inch cylinders and one 6- by 21-inch beam and one slump test.

Strength specimens were cured in moist sand and were broken at 28 days. Beams were broken as cantilevers, two breaks being obtained from each beam. Ten batches with ¾-inch gravel and 10 with 1¼-inch gravel were sampled permitting 20 compression tests and 20 flexure tests for each mixing period for each size of aggregate.

Table 8 shows the results of the strength tests in detail. Table 9 is a summary of the strength results and shows data corresponding to that in table 4 for plant 1. Figure 8 shows graphically the compressive and flexural strengths for the individual specimens made from each batch for each mixing time.

There was some variation in the proportions of the ingredients in the different batches of concrete. This was the result of the use of constant weights in batching with no correction for variations in moisture content of the aggregates. Using the data of table 9 as a basis for determining the effect of the length of the mixing time on the strength of the concrete, the following results are shown:

The average compressive strength of concrete with ¾-inch aggregate, mixed for 4 minutes, is 197 pounds or 9 percent higher than the corresponding strength of the 1-minute concrete. The average compressive strengths increase with the mixing time. The spread in strengths for the four sets of specimens is between 520 and 1,040 pounds.

The average compressive strength of the 4-minute concrete with 1¼-inch aggregate is 118 pounds or 5 percent higher than the corresponding strength of the

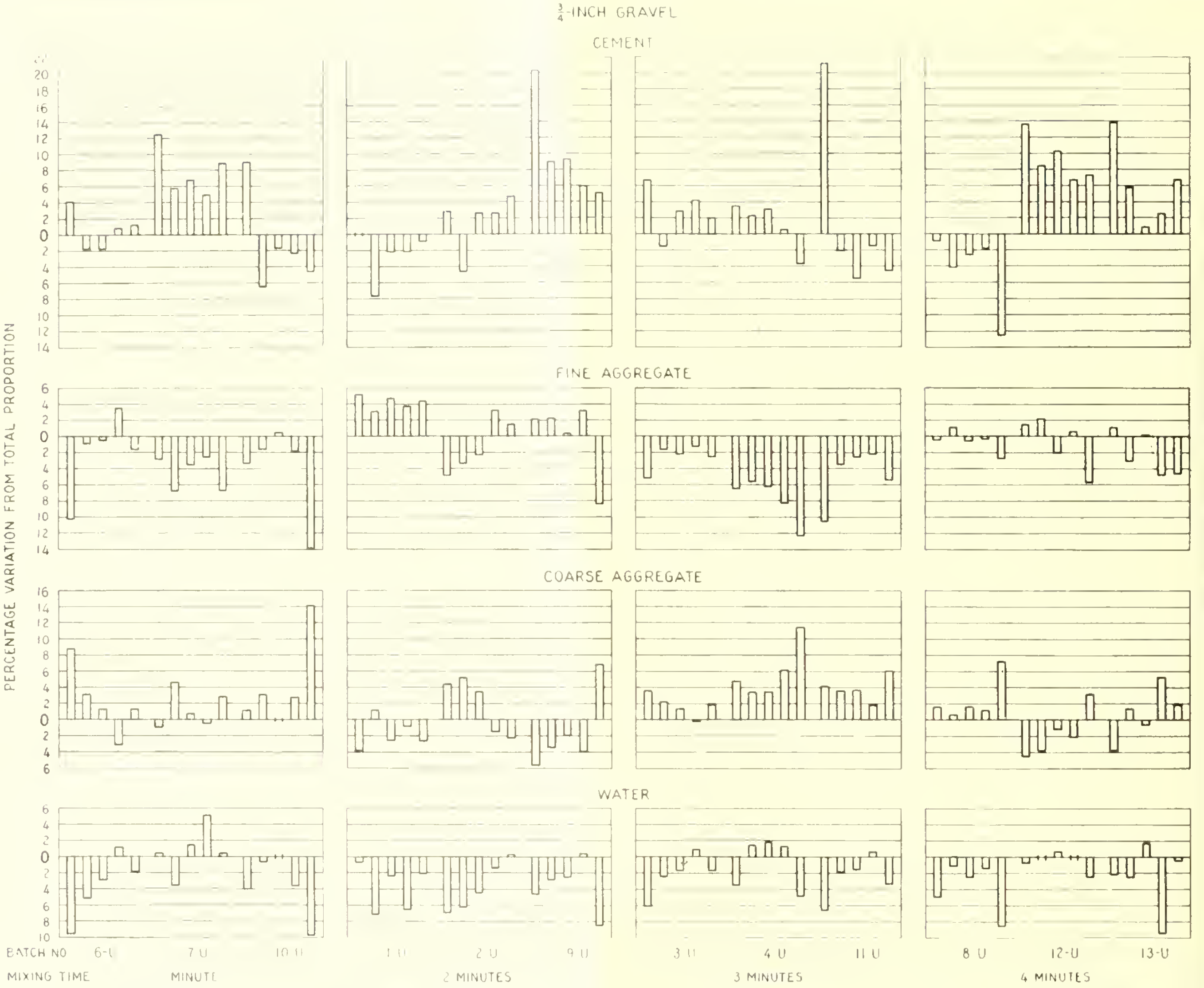


FIGURE 5.—PERCENTAGE VARIATIONS OF MATERIALS IN SAMPLES FROM BATCH PROPORTIONS AS FOUND IN TESTS USING 3/4-INCH GRAVEL AT PLANT 2. SAMPLES FROM EACH BATCH ARRANGED IN ORDER A, B, C, D, AND E.

TABLE 8. *Results of strength tests at plant 2*

CONCRETE WITH 3/4 INCH COARSE AGGREGATE

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
	Inches	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*
1	7¼	2,170 2,350	436 455	7	2,410 2,320	529 520	7½	2,190 2,220	519 528	7	2,380 2,440	455 478
Average		2,260	445		2,365	524		2,205	523		2,410	467
2	6½	2,310 2,510	426 482	4½	2,690 2,640	422 461	7¼	2,550 2,370	449 435	6	2,400 2,550	385 454
Average		2,410	454		2,665	442		2,460	442		2,475	420
3				6½	2,410 2,320	438 482	6¾	2,400 2,260	454 422	7½	1,790 1,910	428 423
Average					2,365	460		2,330	438		1,850	425
4	6	2,150 2,160	442 449	6	2,330 2,130	451 486	6	2,570 2,380	424 495	6	2,430 2,640	486 474
Average		2,155	446		2,230	468		2,475	460		2,535	480

TABLE 8.—*Results of strength tests at plant 2*—Continued

CONCRETE WITH ¾-INCH COARSE AGGREGATE—Continued

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
	Inches	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*
6	6½	2,210	528	8	2,380	390	6½	2,420	456	6	2,390	417
		2,400	448		2,100	476		2,340	444		2,510	469
Average		2,305	488		2,240	433		2,380	450		2,450	443
13	8	2,050	546	8½	2,160	482	7¾	2,340	520	7	2,230	476
		1,930	530		2,150	479		2,350	502		2,350	478
Average		1,990	538		2,155	481		2,345	511		2,290	477
14	7	2,500	521	3¾	2,250	505	4	2,380	510	3½	2,630	446
		2,490	530		2,140	538		2,390	521		2,690	496
Average		2,495	525		2,195	522		2,385	515		2,660	471
15	8	2,310	481	9	2,350	468	8½	2,090	402	6¾	2,830	395
		2,420	463		2,170	411		2,410	427		2,690	455
Average		2,365	472		2,110	440		2,250	415		2,760	425
18	7	1,980	513	8½	1,940	410	7½	2,190	440	5¼	2,270	455
		2,010	531		2,170	466		2,050	468		2,390	437
Average		1,995	522		2,055	438		2,120	454		2,330	446
19	8¼	1,940	382	8¾	1,980	418	8½	2,230	430	7	2,310	458
		1,890	434		1,950	464		2,160	426		2,310	496
Average		1,915	408		1,965	441		2,195	428		2,310	477
Grand average		2,210	477		2,265	465		2,315	464		2,407	453

CONCRETE WITH 1¼-INCH AGGREGATE

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
5	8¾	1,780	513	8½	2,290	487	8½	2,210	433	8	2,480	427
		2,130	448		2,230	545		2,190	473		2,280	453
Average		1,955	481		2,260	516		2,200	453		2,380	440
7				6½	2,430	447	6¾	2,390	450	6	2,520	479
						483		2,510	493		2,520	440
Average					2,430	465		2,450	471		2,520	460
8	7½	3,210	490	5¾	2,770	500	5½	3,090	490	4¾	3,020	524
		3,140	559		2,640	475		3,060	507		3,020	472
Average		3,175	524		2,705	488		3,075	498		3,020	498
9	8	2,230	485	8	2,290	424	7	2,460	530	5¾	2,570	394
		2,110	462		2,410	477		2,670	449		2,520	445
Average		2,170	473		2,350	451		2,565	490		2,545	420
10	8	2,500	480	7½	2,690	453	7¼	2,810	442	6½	3,010	459
		2,560	451		2,720	512		3,030	523		2,970	474
Average		2,530	465		2,705	483		2,920	482		2,990	467
11	6¼	2,710	467	7	2,950	480	7¼	2,910	488	6½	2,870	464
		2,680	465		2,890	532		2,750	471		2,950	464
Average		2,695	466		2,920	506		2,830	478		2,910	464
12	8½	2,630	482	7½	2,780	463	6¼	2,440	485	3¾	2,870	367
		2,770	457		2,550	493		2,610	473		2,410	473
Average		2,700	470		2,665	478		2,525	479		2,640	420
16	6½	3,110	530	8	2,450	459	6½	2,630	423	5¼	2,790	502
		3,320	515		2,620	463		2,790	513		2,840	497
Average		3,215	522		2,535	461		2,710	468		2,815	500
17	5¼	2,960	468	5¾	2,440	458	6	2,470	433	4¾	3,050	396
		3,240	511		2,940	463		2,780	473		3,240	462
Average		3,100	490		2,690	460		2,625	453		3,145	429
20	9½	1,730	408	9	2,170	471	8	2,460	443	8½	2,030	467
		1,850	461		2,090	483		2,470	476		2,230	449
Average		1,790	434		2,130	477		2,465	460		2,130	458
Grand average		2,592	481		2,545	478		2,636	468		2,710	455

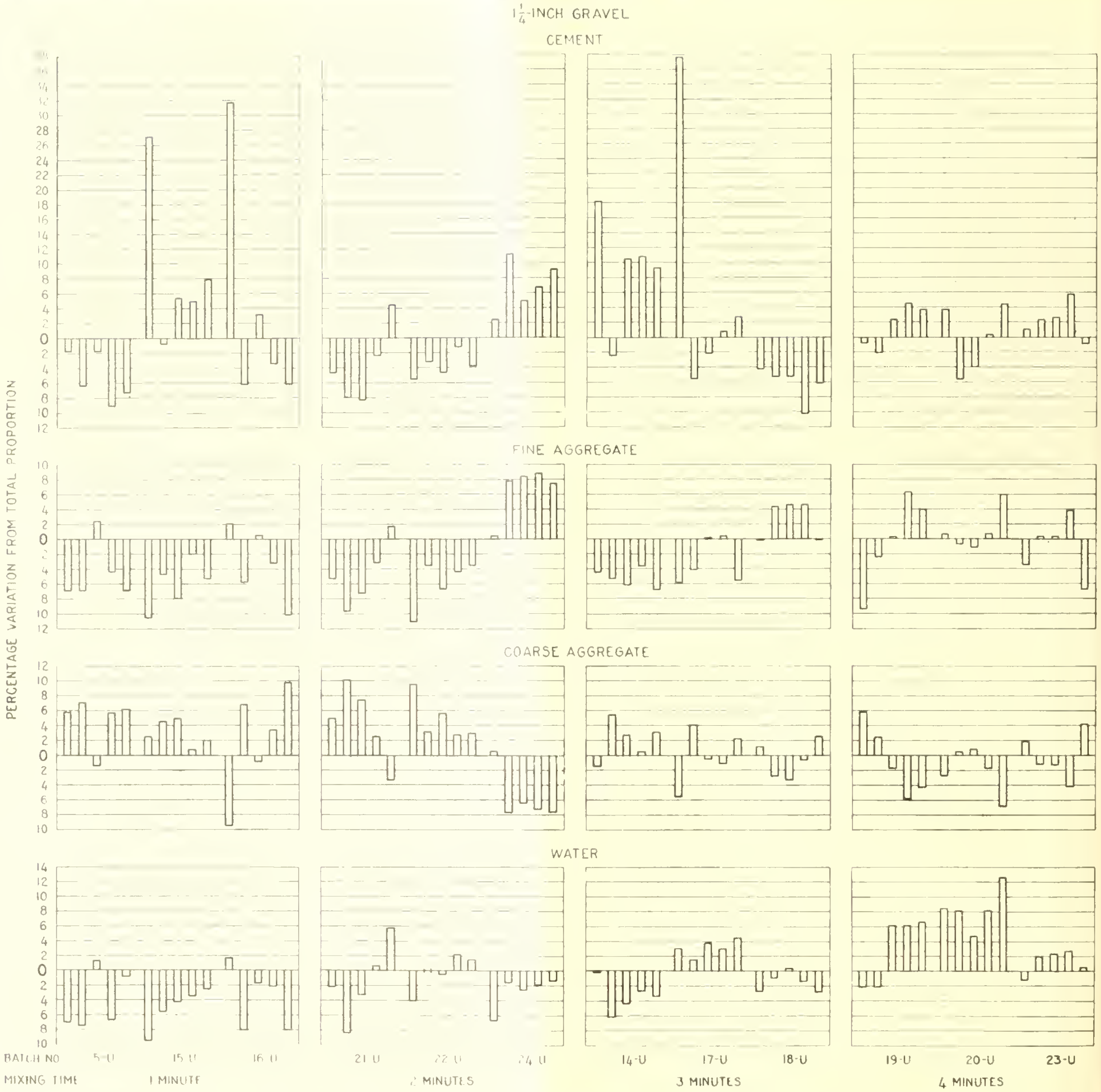


FIGURE 6.—PERCENTAGE VARIATIONS OF MATERIALS IN SAMPLES FROM BATCH PROPORTIONS AS FOUND IN TESTS USING 1¼-INCH GRAVEL AT PLANT 2. SAMPLES FROM EACH BATCH ARRANGED IN ORDER A, B, C, D, AND E.

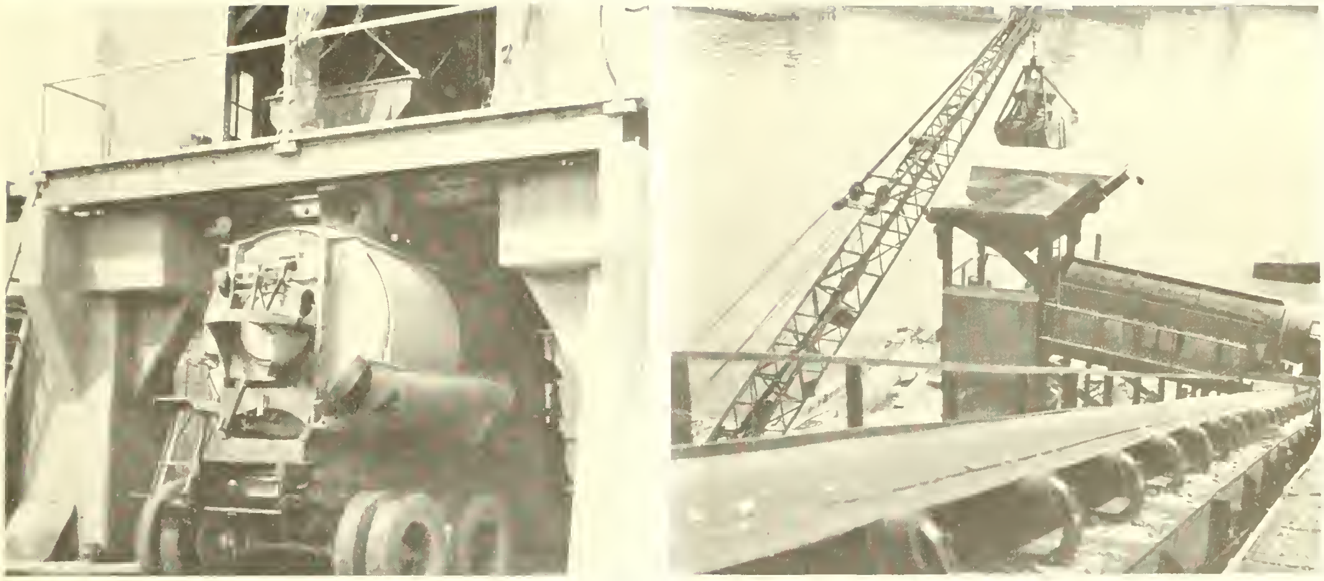
1-minute concrete. With the exception of the 2-minute concrete the average compressive strengths increase with the mixing time. The spread in strengths for these four sets of specimens is between 860 and 1,590 pounds.

The average flexural strength of the 4-minute concrete with ¾-inch aggregate is 5 pounds or 24 percent lower than the corresponding strength of the 1-minute concrete. These average flexural strengths decrease as the mixing time increases. The spread in strengths for these four sets of specimens is between 111 and 164 pounds.

The average flexural strength of the 4-minute concrete with 1¼-inch aggregate is 26 pounds or 5 percent lower than the corresponding strength of the 1-minute concrete. These average flexural strengths decrease as the mixing time increases. The spread in strengths for these four sets of specimens is between 107 and 157 pounds. These results indicate that the length of the mixing time had no appreciable effect on the strength of the concrete.

LESS GRINDING OF FINE AGGREGATE IN TESTS AT PLANT 2

The grinding of the coarse aggregate during the mixing action so that it passed the no. 100 sieve was negligible. The amount of fine aggregate passing the no. 100 sieve before entering the mixer and the amount of fine aggregate passing this sieve after the concrete had been mixed for each of the four mixing periods are shown below.



Equipment at Plant No. 2.

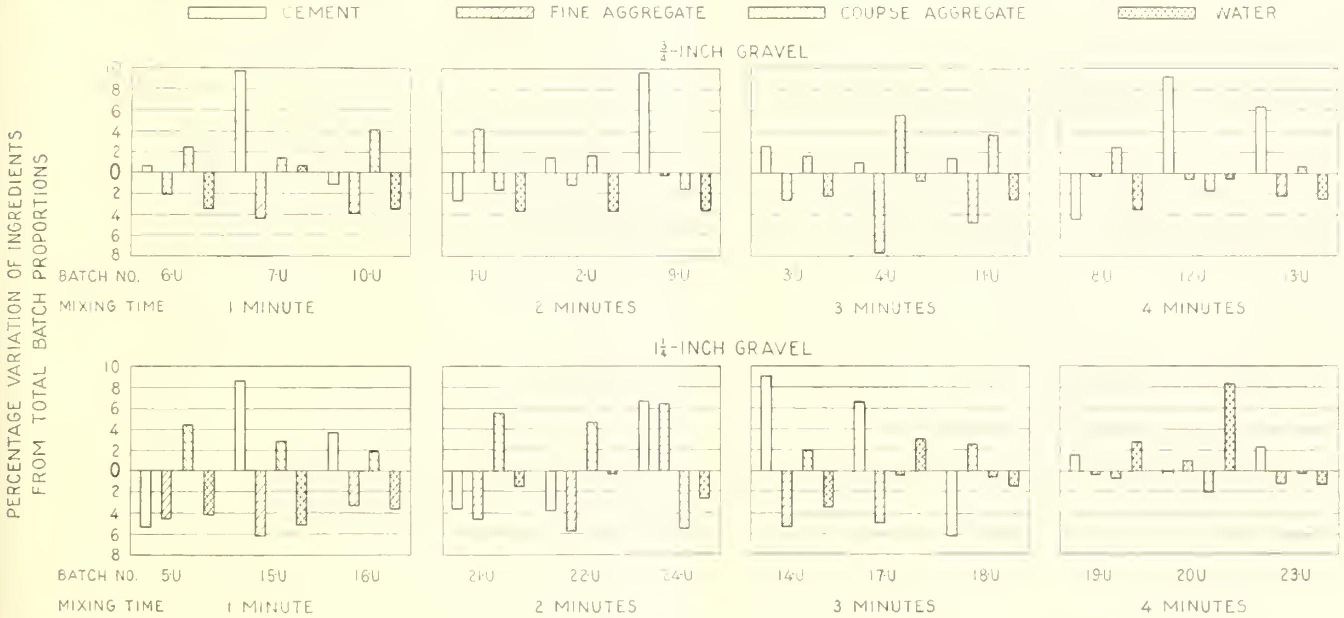


Figure 7.—Percentage Variations of Materials from Batch Proportions Computed for Assumed Samples Composed of Five Samples from Each Batch.

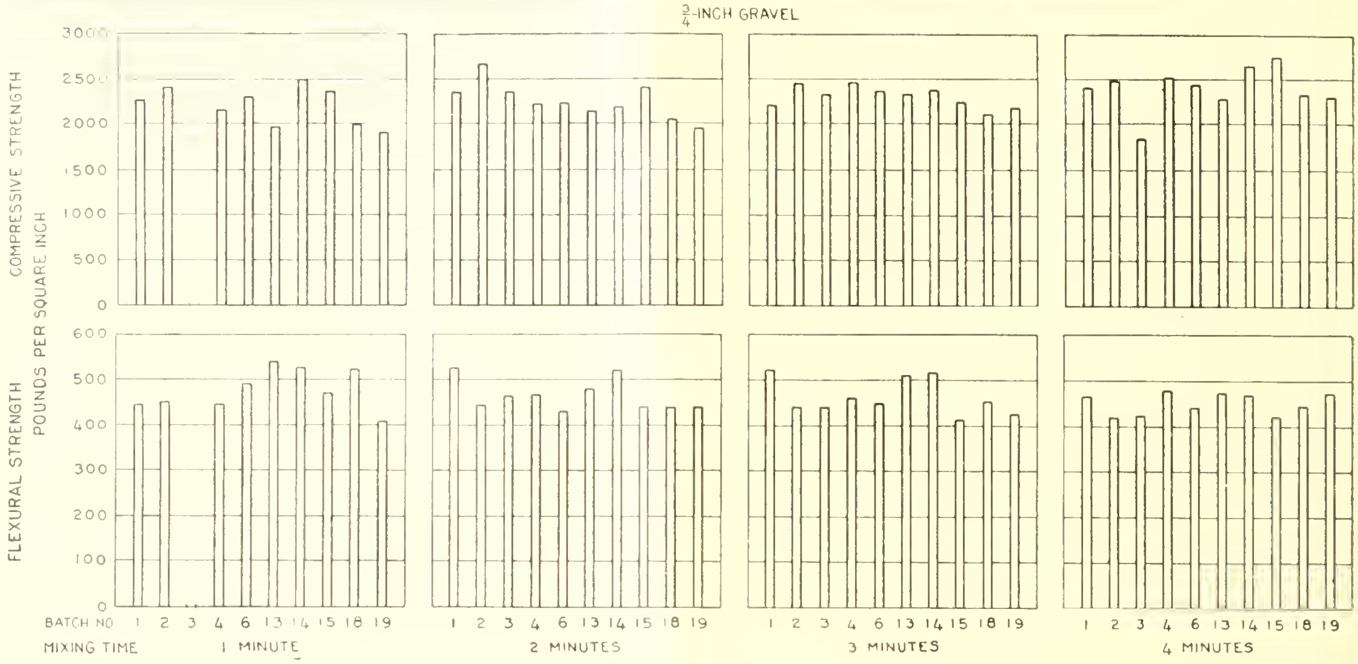
Table 9.—*Summary of results of strength tests at plant 2*

CONCRETE WITH ¾-INCH AGGREGATE

Mixing time (minutes)	Compressive strength				Flexural strength			
	Maximum individual	Minimum individual	Maximum spread	Average	Maximum individual	Minimum individual	Maximum spread	Average
	Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	2,510	1,890	620	2,210	546	382	164	477
2	2,690	1,940	750	2,265	538	390	148	465
3	2,570	2,050	520	2,315	528	402	126	464
4	2,830	1,790	1,040	2,407	496	385	111	453

CONCRETE WITH 1¼-INCH AGGREGATE

Mixing time (minutes)	Compressive strength				Flexural strength			
	Maximum individual	Minimum individual	Maximum spread	Average	Maximum individual	Minimum individual	Maximum spread	Average
	Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	3,320	1,730	1,590	2,592	559	408	151	481
2	2,950	2,090	860	2,545	545	424	121	478
3	3,090	2,190	900	2,636	530	423	107	468
4	3,240	2,030	1,210	2,710	524	367	157	455



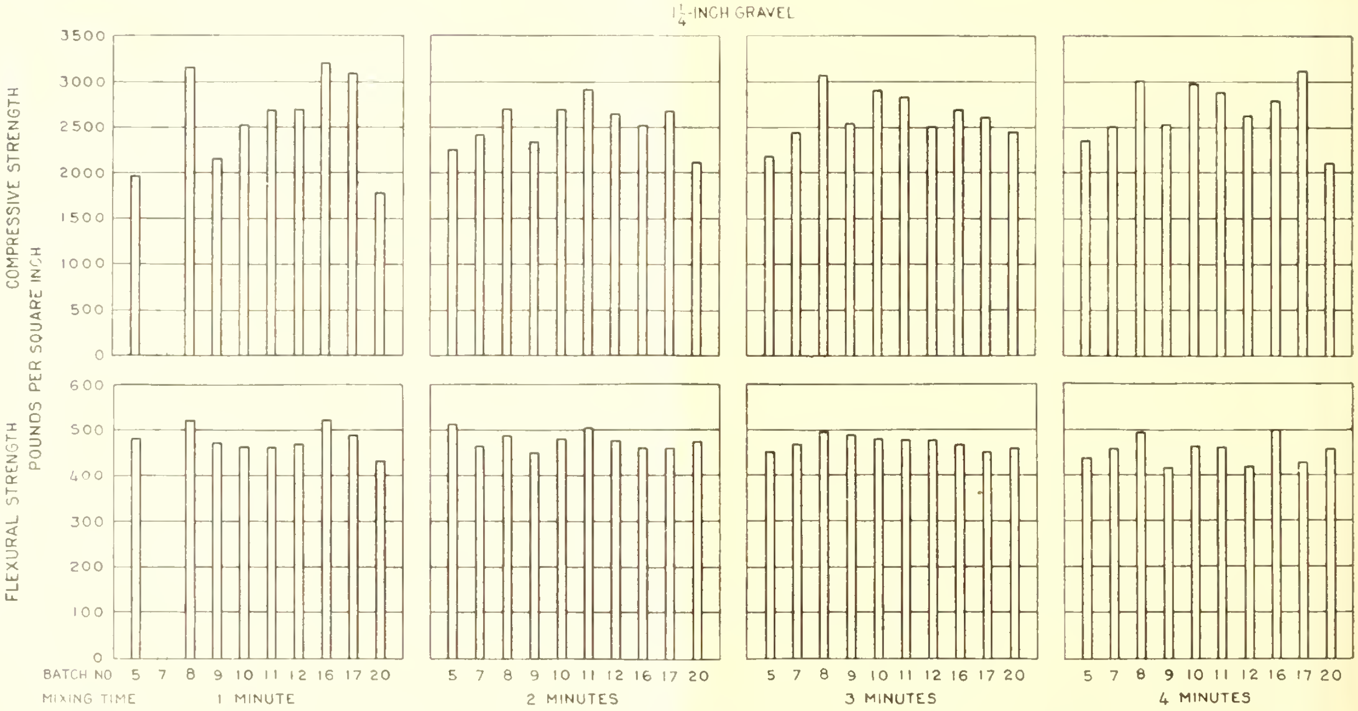


Figure 8.—Compressive and Flexural Strengths Averaged by Batches for All Batches Tested for Strength Plant 2.

Mixing time in minutes:	*Percentage of aggregate passing no. 100 sieve*
0	1.8
1	2.5
2	2.9
3	3.7
4	6.0

CONCLUSIONS

The following conclusions are based on the results of these tests:

1. Standard, revolving drum, batch mixers do not mix concrete so that the cement, aggregates, and water are uniformly distributed throughout all parts of the batch.
2. The degree of uniformity of distribution of the ingredients is not materially changed by changes in the mixing time from 1 to 4 minutes.
3. The length of the mixing time between 1 and 4 minutes appears to have little effect on the strength of concrete as mixed in standard, revolving drum, batch mixers.
4. Standard, revolving drum, batch mixers act as a ball mill in reducing the size of particles of the fine aggregate.
5. The amount of grinding of fine aggregate so that it passes the no. 100 sieve increases with the length of the mixing time.

FURTHER TESTS OF COTTON MATS FOR CURING CONCRETE

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

In the report on the studies of the use of cotton mats for curing concrete pavements, which was published in the July 1933 issue of Public Roads, it was suggested that mats of the type described might be effective as a protection against freezing during sudden drops of air temperature such as occur overnight at certain seasons of the year.

During the past winter several sets of observations were made at the Arlington Experiment Farm which throw some light upon the effectiveness of cotton mats of various thicknesses when used for this purpose.

A number of small 6-inch concrete slabs were cast with their upper surfaces level with the surface of the ground. In the center of the upper surface of each slab a copper constantan thermocouple was embedded at a depth of one-fourth inch. One of these slabs was left uncovered while others were covered with cotton filled mats of the following weights:

Designation:	*Approximate weight of cotton filler in ounces per square yard*
A	10
B	30
C	60
D	90
E	110
F	170

COTTON MATS GIVE EFFECTIVE PROTECTION DURING SHORT FREEZING PERIODS

The mats were made of cotton fiber held in place between sheets of loosely woven covering cloth by stitching or tying. The mats designated as D, E, and F were the 3-, 6-, and 9-ply mats referred to in the previous report.

The slabs were 3 feet square and the covering mats were made 5 feet square in order that they might extend beyond the slab edges and thus avoid the possibility of a circulation of air between the mats and the concrete slabs.

In addition to the slabs covered with the cotton-filled mats, and the bare slab for comparative purposes, one slab was covered with a double thickness of dry burlap, one with 2 inches of dry earth, and one with 4 inches of dry loose straw. Apparatus was placed to determine the temperature of the subgrade 12 inches below the bottom of the bare slab.

The data obtained during three periods of observation at times when relatively large drops in temperature occurred are shown in figures 1 to 4, inclusive. The air temperature fell below 32° F. on only one of these occassions. Figures 1 to 3 show the temperature cycles of the air, tha subgrade, the bare slab, the straw-covered slab, and the slabs covered with the lightest and heaviest weights of cotton-filled mats. Because of the close grouping of the temperatures of all of the slabs covered with the cotton-filled mats the data for the intermediate weights of mats have been omitted. It will be noted that the difference in temperature beneath the heaviest and the lightest mats at no time exceeded 2° F.

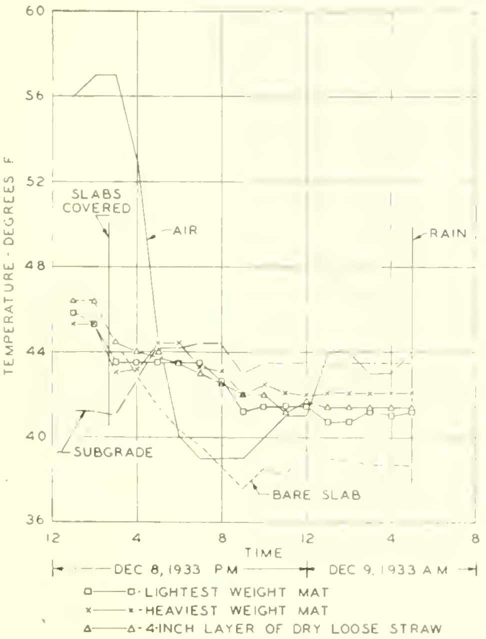


Figure 1.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

The observations made on December 8 and 9, 1933, were terminated by rain which began at about 5 a. m., but on the other two occasions the observations covered a full 24-hour period.

Figure 4 shows a comparison between the temperature cycles of the slabs covered with the lightest weight of cotton-filled mat, 2 inches of dry earth and dry double burlap during the same period as was shown in figure 2, the data being separated for clarity of presentation.

A concrete pavement can acquire or lose heat in either of two directions. The lower surface is in intimate contact with the earth of the subgrade while the upper surface is ordinarily in direct contact with the air. The temperature of the subgrade undergoes annual and diurnal cycles of change similar to those of the air but of lesser magnitude. In the daily changes there is a considerable lag resulting from the low thermal conductivity of the pavement. The lag is evident in all of the data, the temperature of the subgrade rising to a maximum at about the time that the air temperature has fallen to its minimum value.

If a protective cover for a pavement slab is to be effective in preventing freezing of the concrete during a sudden drop in air temperature, two conditions must obtain: First, the subgrade must have a temperature sufficiently above the freezing point of the concrete to provide a flow of heat from the subgrade to the slab; and second, the protective cover on the pavement must provide sufficient insulation to insure that the heat will not be dissipated from the slab surface more rapidly than it is received from the subgrade. It is apparent that the absolute amount of insulation

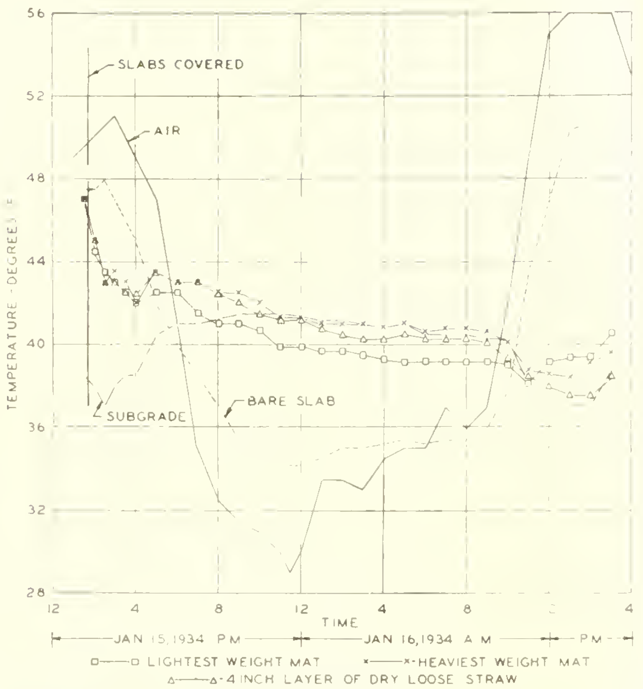


Figure 2.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

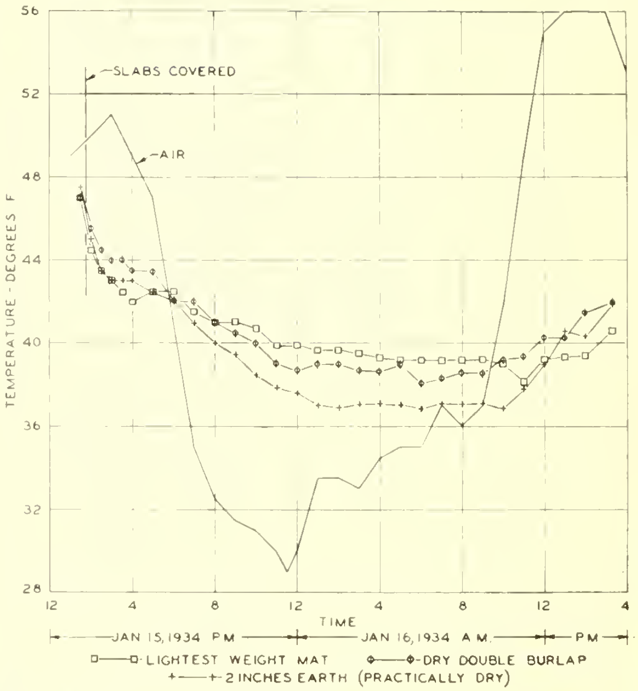


Figure 4.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

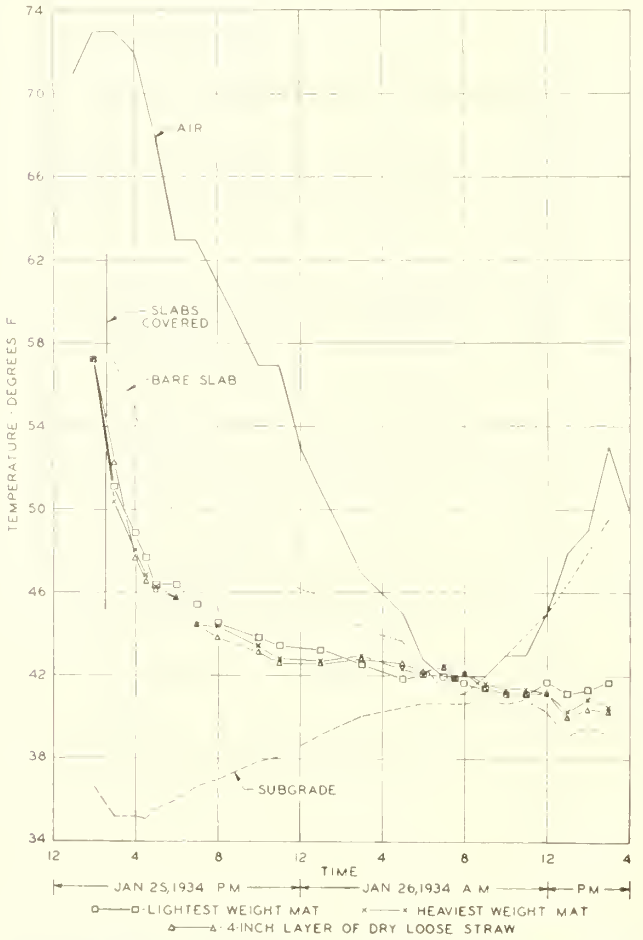


Figure 3.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

required to accomplish this is not a constant but will depend upon the temperature differential existing between the two sides of the protective cover.

In pavement construction it is not the usual practice to place concrete on frozen ground, during freezing weather, or even when freezing temperatures are anticipated. It is to guard against damage due to an overnight drop in air temperature, from a level of possibly 40° or 50° F. to one of 20° or 25° F. that protective covers are most often needed. Ordinarily the temperature of the subgrade is considerably above freezing, the difference between the air and pavement temperatures is not large (from an insulation requirement standpoint at least) and the duration of the subfreezing air temperature is not protracted. For these reasons the requirements for insulation efficiency are not severe. These facts are rather obvious but it is well to bear them in mind when examining the data shown in the accompanying figures.

Probably the most striking indication of these data is that for overnight drops in temperature where a rise on the following day is to be expected, there is but little difference between the protection afforded by the lightest and heaviest of the cotton-filled mats. Both are apparently effective in holding the slab temperature near the temperature of the subgrade during the period of minimum air temperature. It is also indicated, as would be expected, that in case of a protracted period of subfreezing air temperatures neither mat would provide sufficient insulation to hold the temperature of the slab and of the subgrade above the freezing point.

It is interesting to note the similarity of the temperatures of the slabs covered with the cotton-filled mats with those of the slab covered with 4 inches of dry, loose, straw. Although the differences are small it will be noted that the straw cover is consistently more effective than the lightest weight mat and less effective than the heaviest mat.

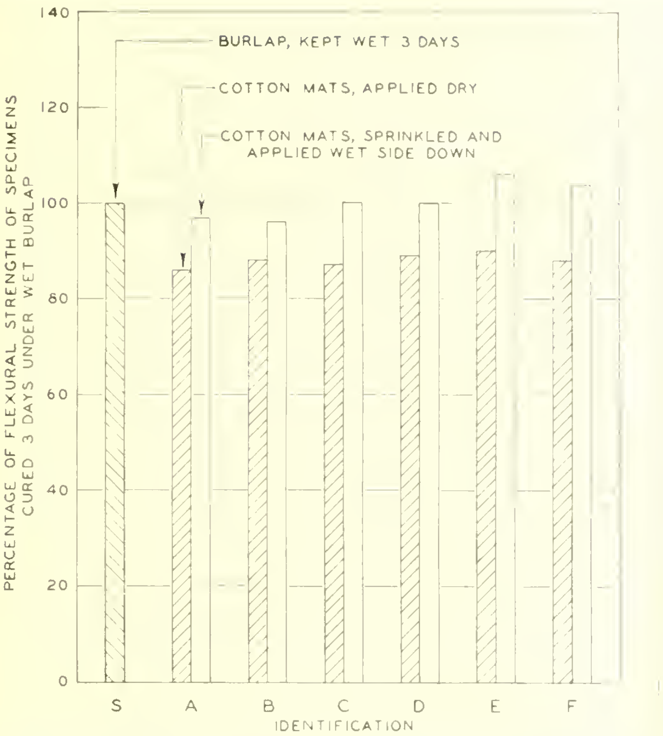


Figure 5.—Comparative Flexural Strengths of Mortar Specimens Cured under Burlap and Cotton Mats.

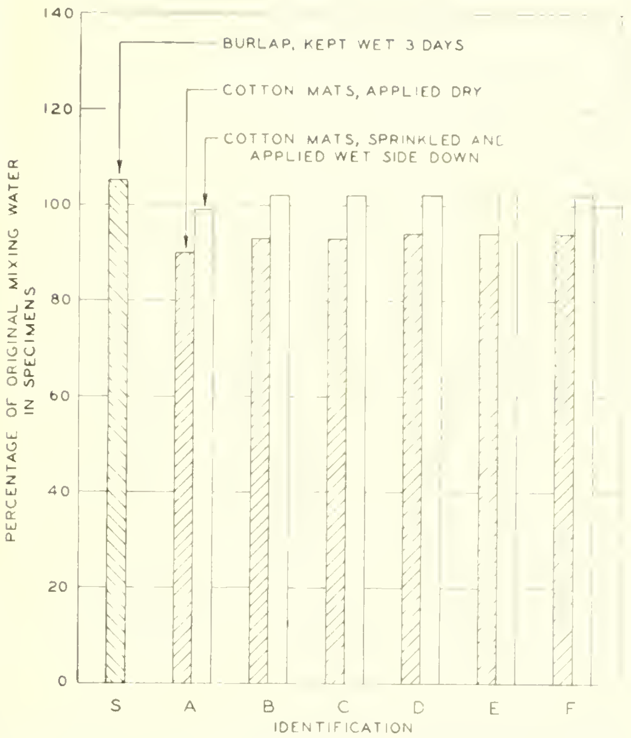


Figure 6.—Comparative Moisture Contents of Mortar Specimens after 3 Days Curing under Burlap and Cotton Mats.

Figure 4 shows data obtained on January 15 and 16, 1934, in addition to those shown in figure 2. These permit a comparison of the lightest weight cotton-filled mat, a covering of dry double burlap, and a 2-inch layer of earth which was practically dry. All of these coverings give some degree of protection, the lightest weight mat being the best of the three. It is apparent from figures 2 and 4 that 4 inches of dry loose straw is a better insulator than 2 inches of earth. The two sheets of dry burlap offer more protection than the earth and less than the cotton-filled mats. The burlap used was a good grade, rather heavy-weight material and was practically new. Being dry, there was a relatively large amount of entrapped air among the fibers. Had this air been replaced by moisture it is probable that the effectiveness of the burlap cover would have been greatly reduced. No data covering this point were obtained.

These few tests do not provide a basis for definite conclusions but it is indicated that, for an overnight drop of air temperature to below 32° F., a considerable amount of protection against damage from freezing can be afforded a concrete paving slab by covering with a cotton-filled mat of relatively light weight.

SPECIMENS TESTED FOR STRENGTH AND MOISTURE LOSS

In addition to the insulation tests, two series of tests were run to determine the flexural strength at 28 days of mortar specimens cured for 3 days under cotton mats of various thicknesses as compared to the strength of similar specimens cured for 3 days under a double thickness of burlap kept continuously wet. Measurements of the gain or loss in moisture of the specimens at the end of 3 days curing as compared to the original water content were also made. In one series the cotton mats were applied dry, while in the other they were thoroughly wet on one side and then applied with the wet side in contact with the specimen. Wetting was done by means of a spray applied to one side of the mat continuously for 10 minutes. The test procedure was identical with that employed in the tests reported last year and was briefly as follows:

The specimens were of 1:2 mortar, by weight, containing 14 percent water. They were cast in watertight molds, 11 inches in length, 6½ inches in width, and 2 inches in thickness. The burlap and cotton mats were applied about 2½ hours after molding. At the end of 3 days the mats were removed and the specimens allowed to cure in the air of the laboratory until the age of 26 days, after which they were immersed in water for 2 days and then tested for flexural strength.

For each series, three rounds of tests were run so that each result as shown in figures 5 and 6 is the average of three determinations, except in the case of the burlap cured specimens where the values shown represent the average of 6 specimens, 3 for each series.

DISCUSSION

The chief purpose of these tests was to compare the curing efficiency of the thinner mats with the comparatively heavy mats (3-ply and over) originally proposed for this purpose. Referring to figure 5 which shows the results of the strength tests, it will be observed that in all cases specimens cured with dry mats showed appreciably lower strengths at 28 days than those cured under the wet burlap. The average strength for all specimens cured under dry mats is roughly 88 percent of the strength of specimens cured by the standard method, which checks approximately the results previously obtained.

The reason for the lower strengths is, of course, the moisture loss suffered by the specimens during the 3-day curing period. These moisture losses, shown graphically in figure 6, average approximately 7 percent of the original water content. On the other hand, the specimens cured for 3 days under wet burlap showed an increase in moisture content of about 5 percent, indicating that water was taken up by the specimens during this period. It may be noted also that the very thin mat designated A, seemed somewhat less effective in retaining water than the others.

In the case of the mats which were thoroughly wet before application, the specimens developed an average strength at 28 days approximately equal to that of specimens cured by the standard method. The thinnest mats (A and B) resulted in slightly lower strengths, while in the case of the thickest mats (E and F) the strengths were slightly above the standard. The differences in strength, however, were not great and the apparent trend may be accidental.

The only specimens to show any moisture loss under the wet-mat curing were those covered by the thinnest mat designated A. In all other cases the specimens showed a gain in moisture content, averaging about 2 percent, or about 3 percent less than the standard burlap-cured specimens. Therefore, from the standpoint of the effect of moisture retention on strength, there is no reason to expect a higher strength for any of the specimens cured with wet mats than was shown by the burlap-cured specimens.

The differences in strength shown by the specimens cured with wet mats, with the possible exception of the strength of those cured with mat A, are not thought to be significant. In this case of mat A a very small water loss was recorded. It is probable that if the two thinnest mats, A and B, had been kept continuously wet during the 3-day curing period, strengths at least as high as the standard would have been obtained.

In any event, the differences are not great enough to affect the conclusion that, within the limits of these tests, substantially the same results are obtained with the various thicknesses of cotton mats as with the wet burlap, provided the mats are wet when applied. However, it should be remembered that these tests were conducted in the laboratory and not under field conditions. Had the mats been subjected to the direct rays of the sun it is quite possible that the thinnest mats would have permitted a higher moisture loss than was noted in the laboratory. Under these conditions the strengths would probably have been lower than was shown by the tests.

In view of this possibility, it is recommended that such mats be used only under the conditions specified for burlap; that is, kept continuously wet during the 3-day curing period.

With these limitations in mind, these tests substantiate the previously published conclusion to the effect that cotton mats of the thicknesses and weights shown, if wet once and applied with the wet side down, are as effective in curing as a double thickness of burlap kept wet continuously for 3 days and also that mats applied dry are less effective than either the wet mats or the burlap.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 3,217,035	$ 1,779,907		143.9	$ 3,632,056	$ 2,004,338	$ 35,889	245.6	$ 58,042	$ 234,036	31.1	$ 105,466	$ 1,859,996
Arizona	3,878,555	1,338,712	3,229,330	3,120,866		231.3	1,832,621	721,725	561,683	94.0	4,655	132,624	10.1	31,309	644,405
Arkansas	3,374,167	1,714,000	1,658,062	1,338,633		68.8	2,105,709	1,855,595		104.8	90,381		.8	89,558	1,714,000
California	7,912,928	3,966,103	6,415,717	4,764,610		223.9	4,866,088	3,142,764		92.9		840,249	12.0	5,554	3,125,854
Colorado	3,437,265	2,424,504	3,011,807	2,991,547		139.3	1,645,476	420,186	1,120,562	73.9		429,012	21.5	25,532	874,930
Connecticut	1,404,213	607,500	189,823	189,823		3.0	1,385,153	1,213,805		27.8	584	498,023	5.4		109,477
Delaware	892,544	461,697	534,663	532,569		12.9	778,119	348,977	413,964	15.8		38,568		10,997	9,166
Florida	2,519,010	1,330,672	2,593,605	1,898,376		87.4	671,195	533,266		29.3	58,425	147,474	5.1	28,945	1,183,198
Georgia	5,045,592	2,556,745	2,622,100	2,599,351		174.6	1,805,833	1,661,688		112.1	103,654		7.3	680,899	2,556,745
Idaho	2,166,858	1,131,910	1,667,250	1,602,139	$ 14,243	161.5	719,507	477,909	190,779	31.9	65,191	207,220	7.0	21,619	719,668
Illinois	4,468,247	3,060,041	1,016,493	1,015,828		23.8	3,132,392	3,040,483	66,025	30.9	411,937	203,180	7.5		2,790,835
Indiana	5,013,921	2,843,478	1,786,187	1,786,187		65.9	2,543,333	2,542,646		69.1	274,201		3.9	415,887	2,843,478
Iowa	5,027,830	2,217,361	4,090,435	3,916,401		219.9	2,122,544	1,083,300	859,845	137.9		797,980	53.5	28,129	559,536
Kansas	5,044,8[illegible]2	2,556,837	4,596,421	4,548,636		388.0	1,166,220	494,856	426,655	92.6	1,310	1,443,776	200.4		688,406
Kentucky	[illegible]	1,527,324	2,456,368	2,430,010		188.9	1,453,201	1,219,454		65.2	102,087	437,595	57.0	54	1,089,729
Louisiana	[illegible]	1,360,419	1,219,648	1,218,415		49.6	1,936,619	1,429,968		28.7	12,232	441,169	7.8	20,537	939,250
Maine	1,617,560	793,644	1,040,886	1,030,005		34.3	899,091	489,260	385,144	18.0		356,4[illegible]	10.9	98,294	52,098
Maryland	1,782,263	289,610	527,930	518,281		10.5	771,257	664,671	106,586	16.0	514,436		8.5	84,874	183,023
Massachusetts	1,101,716	1,632,874	1,087,315	798,064		30.4	330,026	226,326		7.4				77,327	1,632,874
Michigan	6,113,389	3,226,284	2,257,950	2,257,950		103.0	4,203,300	3,806,675	347,625	181.4	40,000	649,975	21.6	8,764	2,228,684
Minnesota	4,561,011	2,642,244	4,033,889	3,832,083	143,462	713.3	1,940,107	718,154	1,205,053	154.8		521,649	74.8	10,775	772,080
Mississippi	3,489,337	2,301,148	2,042,971	1,087,665		111.7	3,446,251	1,895,439		178.4	261,144	645,313	57.2	245,090	1,655,835
Missouri	5,237,532	2,778,183	3,994,052	3,467,044		163.7	2,240,425	1,604,114	506,160	65.7	521	925,737	27.4	165,853	1,346,286
Montana	4,463,849	2,714,208	4,752,589	4,269,577		368.0	1,079,457	175,080	687,460	93.9		829,473	93.6	19,192	1,197,275
Nebraska	3,914,481	1,982,182	4,196,160	3,145,355		289.5	1,294,851	768,306	132,308	87.2		834,754	45.4	820	1,015,120
Nevada	2,909,387	1,350,356	2,315,717	2,272,390		225.8	700,064	570,608	129,457	48.0		352,099	30.6	66,389	868,800
New Hampshire	725,739	484,731	656,954	646,720		10.8	165,251	79,019	73,827	2.3		70,880	1.7		340,024
New Jersey	3,099,371	951,379	986,187	978,648		19.5	2,180,942	2,032,931		27.6				87,792	951,379
New Mexico	2,846,648	1,470,850	2,874,956	2,731,026		274.1	604,060	49,538	554,522	63.7	18,762	593,666	38.9	47,322	322,662
New York	10,465,672	2,872,521	5,634,973	4,850,659		128.4	10,200,979	5,463,772	2,036,400	184.3	83,867	650,080	28.6	67,374	186,041
North Carolina	4,761,147	2,420,471	3,242,435	2,685,983		386.8	1,815,131	1,364,584	223,033	252.4	282,108	365,910	56.8	428,472	1,831,528
North Dakota	2,902,224	1,469,483	2,729,628	2,430,566		888.7	485,817	333,732		99.9	56,509	355,412	174.3	81,417	1,114,071
Ohio	7,277,758	3,539,255	6,281,274	5,997,319		153.8	1,334,350	1,203,403		38.1		1,091,120	24.2	77,036	2,448,135
Oklahoma	4,608,399	2,342,590	3,098,126	3,061,068		228.9	1,271,484	1,265,248		75.0	181,001	451,592	34.5	101,082	1,890,998
Oregon	3,053,448	1,548,906	3,259,987	2,967,249		182.2	724,450	43,707	617,999	37.2	10,790	364,356	10.9	26,701	566,551
Pennsylvania	6,691,194	4,554,082	3,475,594	3,469,559		91.9	4,291,169	3,126,928	817,284	56.0	11,906	1,877,477	44.1	82,801	1,859,321
Rhode Island	979,367	464,572	996,030	933,162		20.5					46,204	215,718	8.1		248,854
South Carolina	2,729,583	1,385,477	1,077,089	1,074,214		98.8	1,705,118	1,614,304	74,381	143.0		42,697	4.3	41,065	1,268,399
South Dakota	3,005,739	1,523,821	2,240,238	1,996,500		374.3	1,149,922	912,894		167.0	85,244		9.5	11,101	1,523,821
Tennessee	4,246,309	2,105,453	3,042,570	2,537,098		123.4	1,611,515	1,436,972	71,689	59.7	246,035	439,835	29.0	26,205	1,593,930
Texas	11,588,643	6,145,627	8,910,718	8,518,665		810.1	2,903,190	2,805,414		202.1	223,868	527,519	50.2	40,695	5,618,108
Utah	2,374,205	1,066,345	2,282,452	2,180,699	30,000	199.2	954,534	156,147	649,880	86.6		28,000	1.4	37,358	358,466
Vermont	928,184	466,042	681,514	649,355		30.5	325,976	268,159	57,000	19.2	10,670	241,637	11.9		167,404
Virginia	3,708,379	1,882,693	2,988,297	2,877,915		133.3	647,796	537,698		10.1	27,139	272,506	15.8	265,628	1,610,188
Washington	3,057,934	1,553,206	2,140,029	2,131,477		83.5	1,255,591	883,426	372,165	31.7	15,918	258,273	6.7	27,112	922,768
West Virginia	2,013,405	1,140,167	1,268,556	1,262,556		40.5	1,224,619	724,650	486,506	50.6	9,320	208,41[illegible]	7.4	16,879	445,249
Wisconsin	4,615,429	2,223,827	3,962,419	3,846,773	500	183.0	993,100	755,783	202,000	58.3		67,528	5.8	12,873	1,953,798
Wyoming	2,250,663	1,143,856	2,272,370	1,979,042	67,583	453.5	934,310	249,276	655,311	115.8		96,3[illegible]7	17.1	[illegible]	324,635
District of Columbia															
Hawaii	1,683,956	598,778	196,115	144,003		10.4	1,824,472	1,471,913		26.5	66,000		.7	2,040	598,778
TOTALS	135,375,363	94,314,089	130,852,914	118,361,968	255,788	9,159.0	87,304,671	59,894,091	14,067,192	3,91[illegible].4	3,374,141	19,185,253	1,382.3	3,745,163	60,805,856

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,032,452	$1,064,960	$141,660	$141,660		11.2	$1,645,596	$1,645,596		117.5	$233,719		13.3	$11,478	$1,064,960
Arizona	525,423	998,032	532,326	520,199		42.3	43,151		$38,779	4.2		$72,129	9.1	5,223	887,124
Arkansas	1,484,634	857,024	386,277	386,023		85.7	834,792	834,540		63.1	126,995		11.9	137,076	857,024
California	3,480,440	1,983,051	2,633,976	2,207,363		121.0	1,305,103	1,102,369		57.6	170,708	135,400	5.7		1,847,651
Colorado	1,718,632	871,502	1,534,805	1,499,932		152.7	826,136	130,000	219,868	148.5		84,686	6.0	28,700	566,948
Connecticut	659,120	420,868					664,916	659,120		14.5					420,868
Delaware	448,864	230,849	20,825	20,825			359,115	263,305	95,810	35.3	164,733	94,702	24.4		40,337
Florida	1,302,816	665,335	1,099,164	1,096,571		67.0	181,681	181,681		7.8		307,694	11.0	24,563	357,641
Georgia	2,320,973	1,278,373	758,544	758,544		66.1	717,591	717,591		59.0	411,249		21.4	433,589	1,278,373
Idaho	1,121,562	824,450	975,778	922,800		124.8	386,797	198,762	169,218	42.4		256,128	25.6		399,104
Illinois	5,410,040	3,345,525	1,288,914	1,287,340		89.4	4,088,891	3,981,326	107,565	235.9	126,849	1,215,599	66.7	14,525	2,022,362
Indiana	602,271	209,900	123,526	123,526		7.1	475,245	475,245		69.7	3,500				209,900
Iowa	2,413,358	1,590,000	1,185,309	1,137,750		158.8	1,477,943	1,193,850	115,900	199.9	38,200	615,900	185.0	43,558	858,200
Kansas	2,522,401	1,279,419	1,139,988	1,139,628		109.2	1,423,935	1,382,773	41,162	80.0		857,545	94.2		380,711
Kentucky	1,837,926	1,336,409	1,447,143	1,427,762		176.8	408,547	407,162		38.9		600,839	66.1	3,002	735,571
Louisiana	1,398,862	838,953	392,358	392,078		21.0	819,553	819,553		28.1	62,079		10.3	125,152	838,953
Maine	842,479	427,897	913,935	829,471		73.8	380,666	5,000	375,666	34.2		14,254	.8	8,008	37,976
Maryland	891,132	1,067,934	547,146	547,146		43.1	413,472	310,953	88,593	26.1	8,541	208,838	9.4	24,492	770,503
Massachusetts	488,185	870,000	367,128	367,128		11.5	102,614	102,614		3.7				18,443	870,000
Michigan	3,184,057	1,613,142	1,145,700	1,145,700		83.9	2,075,630	2,005,730	55,000	143.9		77,900		32,627	1,480,242
Minnesota	2,376,415	1,361,813	1,937,784	1,925,939		195.5	651,948	406,751	142,797	48.0	5,000	281,448	22.8	38,725	937,568
Mississippi	1,744,669	354,022					1,308,456	1,308,456		142.3	262,337		23.8	173,876	354,023
Missouri	2,923,273	1,852,122	2,372,385	2,333,795		466.4	608,877	485,548	123,330	102.0	31,337	739,457	238.3	72,594	989,335
Montana	1,859,937	942,434	1,862,628	1,852,179		226.1						196,412	12.8	7,758	746,022
Nebraska	1,957,240	991,091	1,133,084	1,131,917		172.8	1,197,598	774,004	423,344	139.4		130,372	114.9	51,320	437,374
Nevada	1,136,479	852,000	942,370	941,736		96.7	335,684	141,930	123,385	38.3				52,813	728,615
New Hampshire	477,460	242,365	361,321	320,333		18.5	199,796	156,630	43,166	9.2		46,396	2.4	497	152,803
New Jersey	56,550	460,000	56,550	56,550		.5									460,000
New Mexico	1,272,129	735,425	1,040,951	1,040,951		187.6	205,164	205,164		32.5		78,376	18.8	26,014	657,049
New York	3,608,768	4,252,400	1,664,926	1,554,851	$4,200	42.6	4,551,950	2,041,475	1,508,200	126.6		540,000	39.0	12,442	2,200,000
North Carolina	2,380,573	1,210,235	1,604,153	1,603,375		149.7	520,199	485,672	34,527	80.2	221,132	250,507	33.2	70,393	925,201
North Dakota	1,451,112	734,742	476,386	476,386		123.8	496,262	496,262		192.0	156,213		59.3	322,251	734,742
Ohio	3,871,148	1,966,253	3,210,759	2,989,855		275.8	956,710	825,793	39,400	34.9	55,500	16,400	2.0		1,910,453
Oklahoma	2,304,199	1,171,295	775,830	772,276		136.0	1,550,848	1,479,905		135.1	36,825		6.5	15,192	1,171,295
Oregon	1,526,724	774,454	1,309,653	1,140,753		98.0	409,651	376,968	13,322	11.8		419,376	35.1	9,004	341,756
Pennsylvania	7,344,822	2,639,003	4,486,689	4,455,145		395.5	3,637,057	2,884,052	697,795	308.5	5,625	754,808	24.9		1,186,400
Rhode Island	439,716	295,000	311,329	311,329		26.2	101,136	101,136		7.0				27,251	295,000
South Carolina	1,364,791	692,739	639,106	639,106		68.4	597,275	597,275		76.3	54,249	66,601	9.0	74,161	626,137
South Dakota	1,502,870	761,911	972,551	972,551		278.2	424,628	424,628		115.2	105,691		54.2		761,911
Tennessee	2,123,155	1,075,748	1,093,686	1,074,462		95.7	887,896	887,896		49.7	95,909	241,040	16.5	64,888	834,708
Texas	6,012,518	3,072,813	4,843,090	4,396,419		655.7	1,537,498	1,503,599		111.0	112,500		.3		3,072,813
Utah	1,043,677	533,173	930,376	849,709	18,000	146.6	397,202	187,945	158,815	71.5				11,022	356,358
Vermont	438,880	241,354	241,226	228,439		16.9	293,597	210,441	48,768	22.8		114,822	7.3		77,765
Virginia	1,699,920	941,347	1,183,454	1,140,929		171.9	522,733	493,980		33.4	11,450	88,960	11.4	53,561	852,387
Washington	1,080,673	776,603	798,173	780,915		53.6	299,031	299,031		14.1		34,467	2.0	727	742,136
West Virginia	1,118,559	570,083	254,836	247,758		9.3	752,311	727,177		44.6	84,518		3.3	59,107	570,083
Wisconsin	2,425,385	1,482,551	1,967,961	1,844,514		144.2	647,271	482,656	72,857	29.7	94,317	161,449	9.2	3,898	1,248,246
Wyoming	1,125,332	571,928	1,093,342	1,072,650		147.5	31,654	15,200	15,352	4.9		89,303	8.1	37,482	467,273
District of Columbia	950,234	730,382	645,466	645,466		5.6	478,389	286,117	192,272	4.6		46,263	.2	18,652	491,846
Hawaii	187,106	351,000					177,718	177,718		4.9				9,388	351,000
TOTALS	92,494,941	54,409,909	54,849,567	52,751,734	22,200	5,855.7	42,409,913	34,940,579	4,944,891	3,400.8	2,679,176	8,838,071	1,316.2	2,123,452	40,604,747

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,328	$ 1,064,961	$ 690,033	$ 690,033		15.8	$ 1,431,678	$ 1,431,678		45.8	$ 85,150		1.7	$ 183,066	$ 1,064,961
Arizona	807,982	305,191	514,898	514,133		12.6	[illegible]	105,318	$ 6,592	.6	134,051	$ 30,635	1.6	54,480	267,963
Arkansas	1,889,534	857,025	1,014,458	927,912		27.3	[illegible]	846,420		16.4	115,202		1.4		857,025
California	4,213,986	1,983,052	3,003,723	2,652,781		35.5	1,900,735	1,547,993		17.2		222,000	1.8	13,213	1,761,052
Colorado	1,718,633	190,000	1,743,175	1,693,217		34.9	46,849	23,394	23,455	2.2				2,021	166,546
Connecticut	802,407	426,500	806,490	802,407		10.2						162,813	1.2		263,688
Delaware	477,680	230,849	301,059	292,778		2.5	229,063	174,903	54,180	5.6	[illegible]			5,082	176,669
Florida	1,410,008	665,336	910,277	673,146		10.3	722,468	721,625		7.9	12,073	26,603	.6	3,163	638,733
Georgia	2,724,620	1,278,373	888,093	887,027		38.9	890,472	890,472		[illegible]	280,978		3.0	666,083	1,278,373
Idaho	1,197,829	321,126	600,374	584,233	$ 2,643	17.0	561,927	540,850	7,000	3.0		40,000	.1	72,746	271,483
Illinois	7,692,483	2,515,835	4,194,238	4,176,496		50.2	3,221,345	3,221,345		20.6	180,009	225,746	2.6	114,632	2,290,089
Indiana	4,416,651	2,035,585	1,339,333	1,335,683		34.5	2,516,177	2,516,177		34.9	240,621		3.4	324,170	2,035,585
Iowa	2,614,472	1,311,000	1,557,845	1,494,464		45.0	914,238	858,408	3,580	9.8	261,600	156,270	10.9		1,151,150
Kansas	2,522,401	1,279,419	2,094,852	2,086,483		35.4	580,706	435,745	107	1.9	173	287,926	7.4		991,386
Kentucky	1,927,828	948,578	709,188	693,874		17.1	665,972	664,862		12.7	440,404	255,119	6.8	128,688	693,459
Louisiana	1,748,577	744,560	549,063	549,063		12.9	907,934	881,341		13.3	93,228	21,233	2.6	224,945	723,327
Maine	909,878	490,045	575,933	573,728		12.3	266,996	266,100		4.5				70,050	490,045
Maryland	891,132	452,514	235,592	231,442		2.1	1,064,342	250,821		2.5				408,869	452,515
Massachusetts	5,007,199	847,600	946,315	904,770		6.5	4,007,709	3,982,733		10.1				119,696	847,600
Michigan	3,438,781	1,613,142	1,357,045	1,354,895		19.3	2,375,150	2,076,400	286,250	25.3	6,461	459,950	3.2	1,025	866,942
Minnesota	3,719,143	1,421,494	2,210,089	2,181,230	1,522	88.2	1,246,020	988,069	257,951	20.3		60,852	8.3	549,844	1,101,169
Mississippi	1,744,669	885,057	421,386	408,926		14.8	670,530	670,530		24.0	260,301	107,937	9.0	404,911	777,119
Missouri	4,019,501	1,543,435	1,631,272	1,509,151		44.5	2,228,169	1,798,654	54,043	13.5	316,213	430,463	5.9	395,483	1,058,929
Montana	1,115,962	113,092	1,053,303	1,053,303		31.8	66,377	42,764		2.6	15,713	27,272	5.2	4,183	85,820
Nebraska	1,957,240	991,091	898,503	890,726		25.7	1,068,416	1,019,425	48,991	8.1		238,181	5.2	47,089	703,919
Nevada	500,051	100,000	309,533	309,533		6.2	195,019	172,014		2.6		1,000		18,504	99,000
New Hampshire	706,640	242,366	700,621	685,137		15.6	156,384		156,384	3.0				21,503	85,982
New Jersey	3,190,113	1,809,500	868,718	868,406		6.3	2,292,475	2,238,342		16.5				83,370	1,809,500
New Mexico	1,674,158	735,425	1,110,242	1,110,242		28.9	594,431	411,223	183,208	10.8	51,015		.5	101,677	552,217
New York	8,255,661	4,203,000	3,356,953	3,318,387		33.3	5,883,204	4,929,556	475,400	34.7		915,900	8.2	7,718	2,811,700
North Carolina	2,380,573	1,210,235	1,730,973	1,728,525		63.5	347,356	331,048	15,730	14.6	206,099	52,048	4.7	114,901	1,142,457
North Dakota	1,451,112	734,742	879,100	878,338		36.2	274,409	274,409		12.9	284,200	743	10.9	14,166	733,999
Ohio	4,335,686	2,359,504	3,829,413	3,395,517		49.8	1,018,270	910,697		9.6		190,000	2.2	29,472	2,169,504
Oklahoma	2,304,200	1,171,295	1,526,479	1,514,844		32.9	491,778	490,998		10.1	272,583		4.1	25,775	1,171,295
Oregon	1,526,724	774,454	1,113,828	1,097,661		22.6	377,473	377,473		5.2	30,841		.6	20,749	774,454
Pennsylvania	4,854,988	2,397,703	2,806,056	2,741,310	1,500	48.3	2,005,155	1,878,560	100,855	13.7	163,752	441,970	10.7	71,366	1,853,378
Rhode Island	579,625	255,000	393,937	393,038		6.4	148,206	148,206		1.0				38,381	255,000
South Carolina	1,364,791	692,738	485,674	485,269		15.2	681,858	681,858		26.3	52,573	4,464	1.5	145,092	688,275
South Dakota	1,502,870	761,911	1,036,479	1,036,478		34.9	122,113	122,113		4.9	71,580		1.8	272,699	761,911
Tennessee	2,123,155	1,121,790	1,289,525	1,287,502		19.6	560,116	560,116		5.4	254,550	71,313	3.6	20,988	1,050,476
Texas	6,642,863	3,072,813	3,181,706	3,088,727		90.0	2,351,258	2,342,481		24.7	908,416	21,024	5.3	303,240	3,051,790
Utah	771,826	533,173	670,705	644,383		16.6	122,508	8,700	99,829	5.1		60,000	2.6	118,743	373,343
Vermont	500,509	240,611	414,449	393,500		11.6	111,734	107,009		2.9					240,611
Virginia	2,008,458	941,347	[illegible]	1,194,634		23.9	649,868	465,296		1.1	57,612	155,688	3.4	290,916	785,658
Washington	1,977,260	776,603	1,584,811	1,567,840		29.9	465,741	370,864	94,877	5.5		92,772	2.4	38,557	588,953
West Virginia	1,342,270	570,085	508,131	508,131		10.8	842,261	792,662	25,253	10.5				41,476	544,832
Wisconsin	2,684,067	1,235,459	[illegible]	2,148,738		46.3	525,988	450,505	66,146	8.4		13,743	1.5	84,823	1,155,571
Wyoming	1,125,332	571,928	768,420	767,913		19.6	361,845	357,419	3,845	5.0		3,021	.3		565,062
District of Columbia	968,234	243,460	596,475	596,475		3.9	587,074	357,994	229,080	2.7				13,765	14,381
Hawaii															
TOTALS	116,179,696	51,276,002	62,814,881	60,922,489	5,665	1,317.6	49,738,871	44,735,570	2,192,756	565.5	4,800,317	4,776,686	146.2	5,671,320	44,300,895

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 4,048,727	$ 2,611,600		170.9	$ 6,709,330	$ 5,081,612	$ 35,889	408.9	$ 376,911	$ 234,036	46.2	$ 300,010	$ 3,989,917
Arizona	5,211,960	2,641,935	4,276,554	4,155,198		286.1	1,989,578	827,043	607,055	98.8	138,706	235,389	20.8	91,012	1,799,492
Arkansas	6,748,335	3,428,049	3,058,797	2,652,563		181.8	3,815,749	3,536,556		184.4	332,577		14.1	226,634	3,428,049
California	15,607,354	7,932,206	12,053,416	9,624,753		380.4	8,071,927	5,793,125		167.7	170,708	1,197,649	19.5	18,767	6,734,557
Colorado	6,874,530	3,486,006	6,289,787	6,184,696		326.8	2,518,460	633,580	1,363,884	224.6		513,698	27.5	56,253	1,608,424
Connecticut	2,865,740	1,454,868	996,313	992,230		13.2	2,050,069	1,872,925		42.3	584	660,835	6.6		794,033
Delaware	1,819,088	923,395	856,547	846,172		15.4	1,366,316	787,185	563,953	56.6	169,652	133,270	24.4	16,079	226,172
Florida	5,231,834	2,661,343	4,603,047	3,668,093		164.6	1,575,345	1,436,572		45.0	70,498	481,771	16.7	56,671	2,179,572
Georgia	10,091,185	5,113,491	4,268,736	4,244,982		279.7	3,413,896	3,269,752		196.6	795,881		31.8	1,780,571	5,113,491
Idaho	4,486,249	2,277,486	3,243,402	3,109,172	$ 16,886	303.2	1,668,231	1,217,522	366,997	77.3	65,191	503,348	32.7	94,365	1,390,255
Illinois	17,570,770	8,921,401	6,499,645	6,479,664		163.4	10,442,628	10,243,154	173,590	287.4	718,795	1,644,525	76.8	129,157	7,103,286
Indiana	10,037,843	5,088,963	3,249,045	3,245,396		107.4	5,534,755	5,534,067		173.7	518,322		7.3	740,057	5,088,963
Iowa	10,055,660	5,118,361	6,833,589	6,548,615		423.7	4,514,725	3,135,558	979,325	347.6	299,800	1,570,150	249.4	71,687	2,568,886
Kansas	10,089,604	5,117,675	7,831,260	7,774,748		532.6	3,170,861	2,313,373	467,925	174.5	1,484	2,589,247	301.9		2,060,503
Kentucky	7,517,359	3,818,311	4,612,699	4,551,647		382.8	2,527,719	2,291,478		116.8	542,491	1,293,552	129.9	131,744	2,524,759
Louisiana	5,828,591	2,963,932	2,161,069	2,159,556		83.5	3,664,107	3,130,862		70.1	167,539	462,402	20.6	370,634	2,501,530
Maine	3,369,917	1,711,586	2,530,754	2,433,205		125.4	1,546,754	760,360	760,811	56.7		370,656	11.7	176,352	580,119
Maryland	3,564,527	1,810,058	1,310,668	1,296,869		55.7	2,249,072	1,226,445	195,179	44.6	522,977	208,838	17.9	518,235	1,406,041
Massachusetts	6,597,100	3,350,474	2,400,758	2,069,962		48.4	4,440,348	4,311,672		21.2				215,466	3,350,474
Michigan	12,736,227	6,452,568	4,760,695	4,758,545		206.3	8,654,080	7,888,805	688,875	350.6	46,461	1,187,825	24.8	42,416	4,575,868
Minnesota	10,656,569	5,425,551	8,181,763	7,939,252	144,984	996.9	3,838,075	2,112,973	1,605,802	223.1	5,000	863,948	105.9	599,344	2,810,817
Mississippi	6,978,675	3,540,227	2,464,357	1,496,591		126.5	5,425,237	3,874,425		344.8	783,782	753,250	90.0	823,877	2,786,977
Missouri	12,180,306	6,173,740	7,997,710	7,309,990		674.6	5,077,471	3,888,316	683,533	181.1	348,070	2,095,657	271.6	633,930	3,394,550
Montana	7,439,748	3,769,734	7,668,520	7,175,059		625.8	1,145,835	217,843	687,460	96.5	15,713	1,053,157	111.5	31,133	2,029,117
Nebraska	7,828,961	3,964,364	6,227,747	5,167,998		488.0	3,560,865	2,561,734	604,644	234.7		1,203,307	165.5	99,229	2,156,413
Nevada	4,545,917	2,302,356	3,567,621	3,523,659		328.7	1,230,767	884,553	252,841	88.9		353,099	30.6	137,706	1,696,415
New Hampshire	1,909,839	969,462	1,718,896	1,652,189		44.9	521,432	235,650	273,377	14.6		117,276	4.1	22,000	578,809
New Jersey	6,346,039	3,220,879	1,911,455	1,903,604		26.4	4,473,417	4,271,273		44.0				171,162	3,220,879
New Mexico	5,792,935	2,941,700	5,026,149	4,882,220		490.5	1,403,655	665,925	737,729	106.9	69,777	672,042	58.3	175,013	1,531,928
New York	22,330,101	11,327,921	10,656,853	9,723,897	4,200	204.3	20,636,132	12,434,803	4,020,000	345.6	83,867	2,105,980	75.7	87,534	5,197,741
North Carolina	9,522,293	4,840,941	6,577,560	6,017,883		600.0	2,682,686	2,181,304	273,290	347.3	709,340	668,465	94.7	613,766	3,899,186
North Dakota	5,804,448	2,938,967	4,085,114	3,785,289		1,048.7	1,256,487	1,104,402		304.8	496,922	356,155	244.5	417,834	2,582,812
Ohio	15,484,592	7,865,012	13,321,447	12,382,691		479.4	3,309,330	2,939,893	39,400	82.6	55,500	1,297,520	28.4	106,508	6,528,092
Oklahoma	9,216,798	4,685,180	5,400,435	5,348,188		397.8	3,314,109	3,236,152		220.1	490,409	451,592	45.2	142,049	4,233,588
Oregon	6,106,896	3,097,814	5,683,467	5,205,663		302.9	1,511,574	803,148	631,321	54.1	41,631	783,732	46.7	56,454	1,682,761
Pennsylvania	18,891,004	9,590,788	10,768,339	10,666,014	1,500	535.7	9,933,381	7,889,540	1,615,934	378.2	181,284	3,074,256	79.6	154,167	4,899,098
Rhode Island	1,998,708	1,014,572	1,701,296	1,637,530		53.2	249,342	249,342		7.9	46,205	215,718	8.1	65,632	798,854
South Carolina	5,459,165	2,770,954	2,201,868	2,198,588		182.4	2,984,251	2,893,436	74,381	245.6	106,823	113,762	14.9	260,318	2,582,811
South Dakota	6,011,479	3,047,643	4,249,267	4,005,529		687.4	1,696,663	1,459,635		287.2	262,515		65.6	283,800	3,047,643
Tennessee	8,492,619	4,302,991	5,425,782	4,899,061		238.8	3,059,527	2,884,984	71,689	114.8	596,493	752,188	49.1	112,081	3,479,114
Texas	24,244,024	12,291,253	16,940,514	16,003,811		1,555.8	6,791,946	6,651,494		337.8	1,244,784	548,543	55.8	343,935	11,742,711
Utah	4,194,708	2,132,691	3,883,033	3,674,792	48,000	362.4	1,474,244	352,793	908,524	163.3		88,000	3.9	167,123	1,088,167
Vermont	1,867,573	948,007	1,337,190	1,271,294		59.1	731,307	585,609	105,768	44.9	10,670	356,459	19.2		485,780
Virginia	7,416,757	3,765,387	5,393,907	5,213,477		329.1	1,820,397	1,496,975		44.7	96,200	517,154	30.6	610,105	3,248,233
Washington	6,115,867	3,106,412	4,523,013	4,480,232		167.0	2,020,363	1,553,321	467,042	51.3	15,918	385,513	11.0	66,396	2,253,857
West Virginia	4,474,234	2,280,335	2,031,523	2,018,445		60.6	2,819,191	2,244,489	511,759	105.7	93,837	208,412	10.7	117,462	1,560,164
Wisconsin	9,724,881	4,941,837	8,114,840	7,840,025	500	373.5	2,166,358	1,688,945	341,002	96.5	94,317	242,720	16.5	101,594	4,357,615
Wyoming	4,501,327	2,287,712	4,134,132	3,819,605	67,583	620.6	1,327,810	621,895	674,508	125.6		188,651	25.5	59,828	1,356,970
District of Columbia	1,918,469	973,842	1,241,941	1,241,941		9.6	1,065,463	644,111	421,352	7.3		46,263	.2	32,417	506,227
Hawaii	1,871,062	949,778	196,115	144,003		10.4	2;002,190	1,649,631		33.4	66,000		.7	11,428	949,778
TOTALS	394,000,000	200,000,000	248,517,362	232,036,191	283,653	16,332.3	179,453,455	139,570,240	21,204,839	7,878.7	10,853,634	32,800,010	2,844.7	11,539,935	145,711,498

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PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 10 December 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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SOIL TESTS USEFUL IN DETERMINING QUALITY OF CALICHE

Reported by H. S. GILLETTE, Materials Engineer, District 6, Bureau of Public Roads

THE TERM "CALICHE", as used in the United States, is applied to a group of formations consisting principally of calcium carbonate and silica but containing some alumina, iron and magnesium carbonate. Formations occur locally, in relatively thin beds in solid or powdered form, but usually consist of clays and sands more or less thoroughly cemented by calcium carbonate, or of gravels or breccia so cemented, into caliche conglomerate.

They have been found and developed as road material,[1] in extensive areas of the semiarid regions of the southwest, notably in Arizona, New Mexico, northwestern Oklahoma, and western and southern Texas.

They are frequently described as being both calcareous and siliceous. The latter term arises apparently from chemical analyses which do not distinguish the cementing material from the chemical content of siliceous particles of clays or sands which form the base for cementation. However, one deposit in Texas is reported definitely as having silica alone as the cementing material.

The caliches of the United States are not related, unless in general appearance, to the nitrate deposits of Chile, to which the term caliche was originally applied.

Geologically, our caliches are superficial formations, varying from beds of incoherent powder to those of very considerable hardness and a corresponding high degree of cementation. They have limited continuity and are local in extent, but are of widespread occurrence. They vary in thickness from a few inches to 60 feet or more. Occasionally they are surface deposits, exposed by the erosion of wind or water, or, quite rarely, are products of evaporation of standing bodies of water. Their origin has been carefully studied and described by J. F. Breazeale and H. V. Smith.[2]

Most caliches have been formed at various depths beneath the surface and originate probably through evaporation of ascending or descending waters, the former frequently being the result of capillarity.

The following conclusions are from the bulletin cited:

1. Caliche, wherever found in Arizona, was formed by the solution, transportation, and precipitation of calcium carbonate.
2. Water, when charged with carbon dioxide, dissolves calcium carbonate and forms calcium bicarbonate. The calcium bicarbonate is carried in solution and is precipitated as calcium carbonate, or caliche, when the water is evaporated, or when here is a relief in pressure, which drives off carbon dioxide.
3. Caliche strata may be formed beneath the surface of a soil, either by the evaporation of descending surface water or by he evaporation of ascending ground water.
4. Caliche may be formed in a soil by means of plant roots. Plants growing upon the surface absorb soil water for transpiration purposes, and the calcium carbonate that is dissolved in the soil olution is precipitated as caliche.
5. As long as they are permeable to water, caliche strata will move downward in a soil as fast as erosion removes the upper soil urface.
6. Caliche probably is formed upon the surface of a soil by the evaporation of surface or flood water. The formation under such conditions is hastened by the presence of algae and other water plants.

CALICHES VARY IN CHARACTERISTICS

Generally, caliche is white in color. In specific instances, however, this white color may blend to a light pink, a light purplish red, a dark gray, a light brown, or a light ocher-yellow color. Usually, however, these colors bleach out under the effect of moisture and climate when left for any length of time on the surface.

The chemical constituents of caliche vary considerably. This is because the composition of a deposit depends upon the type of material in which precipitation took place, or upon the chemical nature of the salts in the ground water solution, or both. In Texas, the caliches in which silica or calcium carbonate is the predominating constituent are the ones most widely distributed and, by reason of this widespread distribution, are the ones more largely used. However, other caliches, of a different type from a chemical standpoint, are available in restricted areas.

Outside of Texas there are materials, locally defined as caliche, with other cementing mediums. In the Imperial Valley of California a so-called deposit of "caliche" occurs which consists of a gravel conglomerate cemented with sodium chloride. In Chile the so-called caliches are cemented with sodium nitrate—the Chilean saltpeter of commerce.

Caliches used in highway construction may be classified under three general types, according to hardness:

1. *Flourlike caliche.*—This type consists of a fine sand loosely cemented with a fine impalpable powder which, according to chemical analyses, is composed principally of silica or calcium carbonate. Such caliche may be handled or loaded in the pit without plowing or mechanical breaking of any kind. It may be scraped to a loading platform; may be loaded into wagons or trucks with an elevating grader; or may be loaded into wagons or trucks by laborers with shovels without previous mechanical manipulation.

2. *Semihard caliche.*—This type consists of cemented areas interspersed with the flourlike caliche. Beds of this nature have to be broken up with a hard steel plow or hard steel rooter before the material can be loaded into trucks or wagons. Formations can be broken up and loaded with a steam shovel. When placed on the subgrade of a road the large and semihard lumps usually have to be broken up with mauls or hammers.

3. *Hard caliche.*—This type consists of well-cemented strata or conglomerate areas that have to be blasted with powder or dynamite, and broken into lumps of variable size before the material can be loaded from the pit. Usually it must be run through a crusher before it can be used.

The thickness of overburden on these formations varies with the nature of the terrain and presumably with the previous geological history of the locality where it was formed.

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[1] See Caliche as a Surfacing Material, by L. C. Campbell, Western Highways Builder April 1929. A number of articles on this subject have been published in ighway journals of the Southwestern States, and in other technical magazines. A artial bibliography is appended to the report of J. F. Breazeale and H. V. Smith, ted below.

[2] Bulletin No. 131 of the Agricultural Experiment Station, College of Agriculture, niversity of Arizona.

CALICHE DEPOSITS IN TEXAS DESCRIBED

In Live Oak County there is a deposit of flourlike or fine, loosely bound caliche situated at the lower point of a sloping terrain. This deposit has a very thin overburden of disintegrated material locally called soft limestone, the thickness of which is approximately 8 inches. The flourlike caliche can be loaded with an elevating grader without plowing. The pit is 20 or more feet in depth, 200 to 300 feet wide, and approximately 1,100 feet long and can be extended in length, width, and depth.

About 50 miles south of this location in Duvall County test holes have indicated a similar formation several square miles in area on rolling terrain. The only difference noted in this area is a variation in the amount of overburden. Here it varies in thickness from a few inches to 3 feet.

This same type of flourlike caliche occurs in west Texas in Throckmorton County on the surface of the rolling prairies. This formation, however, is shallow in depth, usually ranging from 3 to 7 feet, and is underlain by instead of covered by a disintegrated limestone formation. While in some areas there is no overburden, in others topsoil occurs from 6 to 18 inches in depth. Pits of a similar nature exist in southeast Texas, particularly in Kerr and Gillespie Counties.

Semihard caliche formations occur in numerous areas in Texas. A typical example is the Realitos pit in Duvall County. This pit is over 1,500 feet long, 500 to 800 feet wide, and from 3 to 25 feet in depth. Although some blasting had to be resorted to, nearly all material has been taken out with a large steam shovel without blasting. Material found in this pit consists mainly of large cemented areas and conglomerate strata in the interstices of which is fine flourlike material.

Hard caliche beds occur in a great many west Texas areas and, in some instances, in south Texas. They usually consist of stratified layers and conglomerate beds very firmly bound together with a cementing medium. In all instances the caliche has to be blasted before it can be excavated and has to be run through a crusher and broken into small sizes before being used for highway construction.

The use of caliche for highway construction in Texas has been one of necessity. There are a great many areas in the State, some distance from railroads, where other road materials are scarce or wholly absent. Long and expensive railroad hauls prohibited the use of shipped-in materials and the local caliches were developed for use. The construction methods used in building caliche bases and the tests used to determine the quality of the materials have been developed gradually over a period of years.

The first instance of its use on any considerable mileage of Federal-aid highway work was in Hidalgo County in 1920. Since caliche is confined to a more or less localized area, it had not received the widespread attention in road building literature that had been accorded most materials of construction, and as a consequence no special methods of testing this class of road material had been developed. Therefore, some method of testing had to be devised.

STUDIES MADE TO DEVELOP BETTER TESTS FOR CALICHE

Since tests for determining the cementing value and slaking time had been used for a number of years as a means of determining the quality of binders such as rock dust resulting from crushing, and since calcareous binders approached the composition and character of caliches, it was thought at the outset that these tests could be applied to caliches and used to differentiate between caliches of inferior quality and those of good quality. These methods were used for a number of years for control of caliche materials in Texas.

Within the last two years, however, the chemical composition and physical characteristics as disclosed by the routine subgrade tests of the Bureau of Public Roads have been investigated as a means for determining the probable performance of caliche as a road material.

Chemical analyses disclose the percentages of silica, alumina and iron oxide, calcium carbonate, magnesium carbonate, and ignition loss. The routine subgrade soil tests disclose the grading and constants as follows: Liquid limit, plasticity index, shrinkage limit, shrinkage ratio, centrifuge moisture equivalent, field moisture equivalent, and either the volumetric change or the lineal shrinkage.

The significance of these physical tests and the procedures for making them have been discussed in detail in PUBLIC ROADS.[3]

TABLE 1.—*Results of chemical analyses and physical tests of samples of caliche*

Sample no.	Chemical analyses					Physical tests	
	Silica	Alumina and iron oxide	Calcium carbonate	Magnesium carbonate	Ignition loss	Cementing value	Slaking value
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		*Minutes*
GROUP 1							
1	36.30	4.75	52.60	3.71	2.00	335	15
2	15.65	4.55	73.03	1.17	4.96	92	25
3	12.70	2.20	82.32	1.14	1.25	99	10
4	32.40	5.70	55.70	1.97	4.10	147	15
5	54.05	4.80	35.26	2.54	2.81	342	60+
6	13.90	2.60	80.54	2.50		442	60+
7	9.40	1.95	84.20	3.26	1.07	101	60+
8	18.80	7.85	71.43	1.17	0.95	95	25
9	51.00	8.00	35.89	1.78	3.00	384	30
10	32.15	8.75	55.00	1.55	1.90	249	20
11	10.25	4.20	80.54	1.17	2.60	119	40
12	22.80	10.30	60.18	1.48	2.50	98	20
13	16.50	6.05	71.52	2.95	1.85	120	25
14	26.20	7.25	59.91	1.48	4.62	156	30
GROUP 2							
15	47.30	11.20	34.11	1.78	4.76	294	15
16	47.10	7.90	37.68	3.33	3.44	500+	60+
17	6.00	1.00	90.36	2.59		104	60+
18	60.80	7.45	19.73	8.71	1.70	203	8
19	18.20	2.95	72.50	3.26	2.50	287	45
GROUP 3							
20	66.45	7.50	17.23	3.30	3.45	500+	58
21	75.00	9.60	7.68	2.46	3.35	500+	17
22	51.20	6.35	34.73	2.61	3.20	500+	25
GROUP 4							
23	57.90	5.60	25.00	10.07	1.05	467	17
24	28.10	8.40	56.25	1.55	4.05	500+	60+
25	34.70	7.50	50.57	3.40	3.65	441	9
26	42.10	5.50	44.64	4.77	1.57	464	23
27	53.40	17.80	17.77	2.12	8.07	311	15
28	40.05	9.75	45.00	3.03	2.07	288	28
29	36.40	10.20	43.21	3.03	5.91	480	6
30	78.00	11.50	1.43	1.29	6.55	163	4

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[3] See PUBLIC ROADS, vol. 12, nos. 4, 5, and 7.

The routine tests are supplemented by the flocculation test, which is being investigated for use as a substitute for certain of the routine tests in the examination of particular materials, of which caliche is one. It furnishes information on the maximum porosity of sediments and the presence of colloidal gels. The maximum porosity is disclosed by a voids ratio termed the flocculation factor or a corresponding moisture content termed the flocculation limit.

The flocculation factor is defined as the ratio of pores to solids in a sediment formed in 24 hours from a mixture of 5 cc absolute volume of powdered soil solids thoroughly dispersed in 39 cc of distilled water and 1 cc of chemical deflocculent.[4] The quantity of gel present is indicated by type numbers discussed later in this report.

In order to determine the relative efficiency of the various methods of tests for identifying caliches for road building purposes a number of samples representative of both good and undesirable caliches were obtained from roads and pits in various parts of Texas and tested in the Bureau laboratory at the Arlington Experiment Station.

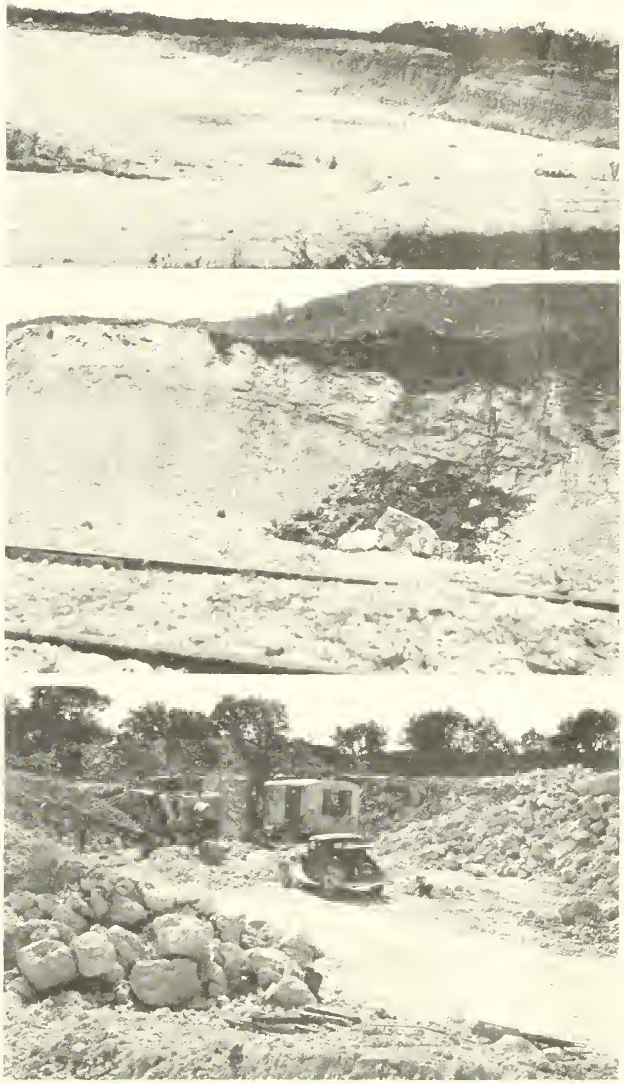
All the samples which could be definitely classified as good or poor base material, according to the performance of the roads in which they were used, were divided into four groups, the first two groups representing the satisfactory caliches, and the third and fourth groups representing the unsatisfactory materials. All the samples represented material in the base courses of roads that had been in service from 3 to 13 years. The chemical analyses and results of the cementing and slaking value tests are shown in table 1. The results of the subgrade soil tests are shown in table 2.

HARD AND SEMIHARD CALICHES GAVE BEST SERVICE

Group 1.—All samples of group 1, except no. 6, were taken from roads in west Texas which have been in use from 3 to 8 years. Each sample was from a base course of 6 or 8 inches compacted depth. These base courses were topped with an asphaltic surface from 1 to 2 inches in depth. All surfacing courses were in excellent condition. One significant feature of this group is that practically all the materials are from pits of hard caliche where most of the material had to be blasted. This, in itself, tended to keep the amount of fine material or binder within safe limits.

In samples, as removed from existing bases, the major amount of material is larger than 2 millimeters in size with a minor amount of excellent binder material containing sufficient cohesive material to thoroughly bind the coarse particles firmly together without detrimental volumetric change. This is not shown in table 2 since in preparing the samples for testing a rubber-covered pestle was used to break down lumps of material.

Group 2.—These materials were collected in south Texas, except sample no. 19, which was from west Texas. The samples were from roads that had been used from 7 to 13 years. All the materials used in these roads were from deposits of semihard caliches which had to be plowed for the most part before excavating. In some few instances strata had to be blasted. All the caliche bases were topped with an asphaltic surface course and in 1933 were in satisfactory condition. The materials of this group will be discussed singly.



DEPOSITS OF FLOURLIKE, SEMIHARD AND HARD CALICHE IN TEXAS.

Sample 15 was taken from a road constructed in 1926. The base course had a compacted depth of 8 inches and was constructed in two layers. The bottom layer was wetted, rolled until thoroughly compacted and permitted to set up before the second course was placed. The same method was used in constructing the second course. Previous to constructing the top course, the base course was bladed even and smooth. This is an important step in preparing caliche bases for top courses, particularly where the traffic is heavy. A major portion of the material, as placed in the road, was above the 2 mm sieve with very little binder. This caliche base was topped with a ¾-inch Uvalde rock asphalt surface course and in 1933 was in excellent condition.

Sample 16 is from a road built in 1927 with semihard caliche containing a high proportion of lumps larger than the 2 mm sieve. The caliche was excavated

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[4] See Proceedings of Twelfth Annual Meeting of the Highway Research Board, p. 62.

TABLE 2.—*Results of soil tests performed on samples of caliche*

Sample no.	Mechanical analyses							Physical characteristics of material passing no. 40 sieve						Volumetric change	Flocculation test	
	Particles larger than 2 mm	Particles smaller than 2 mm						Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Moisture equivalent			Flocculation factor	Type
		2.0 to 0.25 mm	0.25 to 0.05 mm	0.05 to 0.005 mm	Smaller than 0.005 mm	Smaller than 0.001 mm	Passing no. 40 sieve					Centrifuge	Field			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*		*Percent*	*Percent*	*Percent*		
GROUP 1																
1	0	25	30±	(1)	(1)	(1)	(1)	33	0	40	1.3	25	37	0	1.7	1
2	0	39	20	25	16	8	73	20	3	25	1.6	19	21	0	1.7	1
3	0	31	24	29	16	5	80	22	4	21	1.7	18	21	0	1.3	2
4	0	24	38±	(1)	(1)	(1)	(1)	21	5	21	1.7	15	20	0	1.6	1
5	0	26	41	17	16	8	89	24	6	22	1.6	19	23	2	1.3	2
6	0	44	26	18	12	3	67	25	6	33	1.4	19	26	0	1.2	1
7	0	28	18	27	27	9	82	26	6	22	1.7	20	24	3	1.4	2
8	55	22	22	27	29	9	86	26	6	24	1.6	25	23	0	1.6	2
9	28	16	47	20	17	8	91	26	7	25	1.6	18	22	0	1.3	2
10	0	17	23	38	22	6	92	25	8	21	1.7	21	21	0	1.4	2
11	0	22	23	29	26	10	86	26	8	20	1.7	24	23	5	1.5	2
12	0	17	25	28	30	15	92	27	10	18	1.8	24	20	4	1.7	2
13	0	14	20	28	38	9	92	31	13	18	1.8	24	24	11	1.9	1
14	49	20	17	35	28	10	87	36	14	26	1.6	32	31	8	2.2	2
GROUP 2																
15	0	11	42	27	20	10	95	30	8	27	1.5	19	30	5	1.7	2
16	0	19	33	29	19	8	89	34	10	28	1.5	33	31	5	1.7	2
17	0	19	9	53	19	5	88	31	11	19	1.7	28	27	14	1.6	2
18	0	18	50	19	13	7	94	35	12	27	1.6	29	35	13	2.5	3
19	0	6	13	53	28	6	98	38	13	27	1.6	22	34	11	2.0	2
GROUP 3																
20	0	15	53	10	22	14	93	33	17	19	1.7	[2] 80	21	3	7.5	5
21	0	8	64	5	23	17	98	36	21	21	1.7	[2] 88	23	3	7.8	5
22	0	16	40	22	22	13	92	37	23	19	1.7	[2] 77	24	8	6.8	5
GROUP 4																
23	0	18	50	16	16	8	90	40	15	29	1.5	35	35	9	2.8	3
24	0	6	9	35	50	14	97	36	17	24	1.6	31	26	3	1.8	3
25	0	18	28	34	20	8	90	40	18	24	1.6	27	30	10	3.0	4
26	0	4	37	30	29	10	98	46	26	23	1.6	32	34	18	4.7	4
27	0	11	40	19	30	14	93	43	27	15	1.8	27	26	20	3.1	1
28	0	5	28	38	29	11	98	46	28	17	1.7	25	28	19	3.3	1
29	0	12	25	44	19	8	94	52	29	23	1.6	29	32	14	4.0	4
30	0	9	53	6	32	28	99	49	33	20	1.7	29	24	7	7.8	5

---

[1] Flocculated.

[2] Waterlogged.

with a steam shovel and as placed in the road, did not contain an excessive amount of binder.

Samples 17 and 18 are considered together as they were taken from the same highway about 5 miles apart. The road was built in 1920 with caliches of the semihard variety. While some strata had to be blasted with dynamite most of the material was plowed and loaded. An 8-inch compacted base was surfaced with 1-inch of Uvalde rock asphalt. About 1924 the surface was given a light treatment of liquid asphalt. The condition of the surface in 1933 was satisfactory, although some maintenance of edges had been necessary. This road is in a semiarid country; the grades provide excellent drainage and the subgrade is a sand. The temperature very rarely falls lower than 40° F. It is doubtful if this material would be satisfactory for use with a large amount of binder, in regions of heavy rainfall, frosts, and poor drainage or without a thoroughly sealed surface course.

The material represented by sample 19 has an interesting history. The road was built in 1926 when the cementing value and slaking tests were specified as the criteria for quality. At that time very little was known locally about soil physics. The road was in west Texas where caliches are mostly pure white. After the contract was let for the construction of the road, the caliche pit was opened and the material found was of a light pink color instead of white. This was the first pit of pink caliche found in west Texas. Its quality was questioned and considerable concern felt about using it. However, tests were made and the material met the specification requirements as to cementing value and slaking. There were no other pits close at hand and the material was finally used. It is a semihard caliche. Some of the strata had to be blasted, but most of the material was plowed with a tractor.

A base course, 8 inches in compacted depth, was placed late in the fall and allowed to go through one winter without a surfacing course. During wet winter weather the surface became slippery and mucky. In the following summer, after the caliche had dried out and set, it was surfaced with a 2½-inch penetration course with a surface seal coat of liquid asphalt. The seal coat was entirely successful in completely sealing the surface. The grades on this road provide good drainage. At the time of inspection in 1933 this road was in excellent condition.

A Sample of Caliche.

Group 3.—The road from which these samples were taken is in extreme south Texas in a semiarid territory. It was built about 1925 or 1926. Tests of the materials at that time disclosed very high cementation and acceptable slaking properties.

The material was laid to form a base course 6 inches in compacted depth. For 3 years this base course carried traffic without being surfaced. Surface evaporation caused the material to set hard and it gave satisfactory service under traffic. At the end of 3 years the base was surfaced with 1 inch of Uvalde rock asphalt. The rock-asphalt surfacing failed completely in less than a year and had to be removed. This history indicates that caliches of high plasticity, when used in arid regions of high temperatures, with provision for adequate surface evaporation, will set hard and provide good traffic service for up to about 800 vehicles per day. Such caliches may be totally unsatisfactory as bases for a bituminous surfacing. The surfacing prevents evaporation of moisture from the caliche. High capillarity produces considerable water which, if not removed by evaporation, causes loss of stability.

Group 4.—All materials in this group are unsatisfactory caliches. All of the samples were taken from complete failures. Samples of these materials taken from bases beneath asphaltic top courses show high moisture contents and soft cheeselike consistencies with very little stability. In one instance this type of caliche gave reasonably satisfactory traffic service for light traffic during one summer previous to placing the bituminous surface. However, they all failed as a base course for bituminous surfacing.

CHEMICAL ANALYSES AND TESTS OF CEMENTING VALUE NOT SIGNIFICANT

The results of the tests for cementing value show a lack of correlation between test results and field behavior. There is some indication that the better caliches have a lower cementing value and a higher slaking time than the poor materials, but the relations between tests results and field service, in general, are too erratic to be of value.

The chemical analyses illustrate the variable chemical composition of caliches, and also demonstrate the inadequacy of a chemical analysis as a basis for differentiating between the good and poor varieties of caliche. There is dissimilarity in the chemical composition of caliches within the various groups, and also frequent similarity in the compositions of good and poor caliches as, for example, between nos. 14 and 24 and nos. 9 and 22. In general, the better caliches contain more calcium carbonate than the unsatisfactory varieties, but numerous exceptions to this general rule render the chemical analysis ineffective for definitely identifying the satisfactory materials.

GOOD CALICHES HAVE LOW PLASTICITY

In developing a routine procedure for testing soils it has been the aim to develop a sufficient number of tests, varied in character, as to make possible the identification of all the soils apt to be encountered in highway construction. However, in the testing of special surfacing and base course materials, such as limerock, caliche, shale, disintegrated granite and the like, the tests may be limited to those which disclose the particular characteristics upon which the performance of the material depends. These dominating characteristics, as well as the tests which disclose them, may be learned from the results of all the routine tests performed on a sufficient number of samples.

To illustrate, the results shown in table 2 and averaged in table 3 show that the undesirable caliches have higher liquid limits and plasticity indexes than the good materials. The tests for field moisture equivalent, shrinkage limit, volumetric change, and centrifuge moisture equivalent (except in the case of waterlogged materials) do not show consistent differences between good and poor caliches. The poor caliches appear to differ from the good ones mainly in having higher plasticity. Shrinkage as indicated by either the volumetric change or its related constant, lineal shrinkage, seems to be a minor factor in contributing to failure.

Table 3.—*Average results of subgrade soil tests*

Group	Liquid limit	Plasticity index	Shrinkage limit	Centrifuge moisture equivalent	Field moisture equivalent	Volumetric change	Flocculation factor
	Percent		*Percent*	*Percent*	*Percent*	*Percent*	
1	26	7	24	22	24	2	1.6
2	34	11	26	26	31	10	1.9
3	35	20	20	82	23	5	7.4
4	44	24	22	29	29	12	3.8

Considering the test results it seems that a plasticity index less than 15 is sufficient to indicate a caliche satisfactory for road purposes, and that a plasticity index exceeding 15 denotes a material which may prove troublesome. As a supplementary requirement for indicating good caliche the flocculation factor might be limited to 2.5. However, it is possible that either semiarid climate or good drainage may have contributed to the satisfactory performance of several of the caliches represented by the samples with the higher plasticity indexes in group 2. Until more is learned concerning the matter it may be advisable to use caliches with plasticity indexes of, say, 10 to 15 only in fairly dry climates and where subgrade drainage conditions are favorable. In this case flocculation factors up to and including 1.7 would designate materials suitable under general conditions and factors up to and including 2.5 would denote caliches suitable under favorable conditions.

SILICA GEL MAY BE DISTINGUISHING FEATURE OF CALICHE PERFORMANCE

The flocculation factor, resulting from the flocculation test, is useful but the test may serve a more important purpose in disclosing the properties of caliche by indicating the presence or absence of a silica gel.

Sediments of caliches may be of five different types, as follows:

Type 1: No gel, with a clear suspending medium above the sediment.

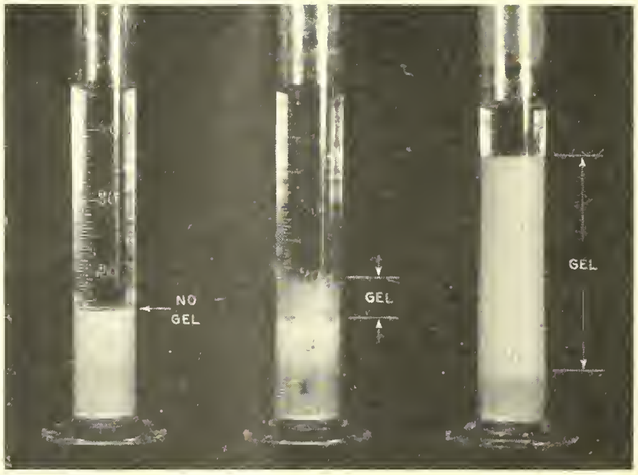
Type 2: Little or no gel, with a cloudy suspending medium above the sediment.

Type 3: Well defined gel, not exceeding about 5 cc in volume; suspending medium clear.

Type 4: Heavy gel, 5 to 15 cc in volume, suspending medium clear.

Type 5: Very heavy gel exceeding 15 cc in volume, suspending medium clear.

Types 1, 3, and 5 are shown in the illustration.



Types 1, 3, and 5 of Caliche Sediments.

From table 2 it can be seen that with but one exception the good caliches, groups 1 and 2, contain little or no gel. Those of group 3 are highly colloidal, as indicated by very heavy gels. This is undoubtedly responsible for the waterlogging in the test for centrifuge moisture equivalent. Oddly enough, however, these gels do not increase the plasticity to the extent which would be expected from the increase in the moisture equivalent.

That the gel, in itself, is not responsible for the high flocculation factors is indicated by the tests on the group 4 samples. Samples 27 and 28, with flocculation factors above 3, have no gel whatever. This indicates that while the presence of a heavy gel may be responsible, in part, for high flocculation factors, as in the case of the group 3 samples, the absence of gel does not necessarily indicate a low flocculation factor.

The gel occurring in caliches is, to all appearances, the same as that produced by the bentonite colloids, which act as emulsifying agents on bituminous materials. Consequently, this silica gel, acting as an emulsifying agent, may be responsible for the failures of processed surfaces and thin bituminous surfaces on caliche bases. Except for the presence of this gel, the soil tests disclose no reason for such failures on caliches.

This leads to the general indications (1) that caliches with plasticity indexes less than about 10, with flocculation factors not exceeding 1.7, and without the gel-producing colloids should prove satisfactory as bases for thin bituminous surface treatments under average moisture conditions; (2) that caliches with plasticity indexes of 10 to 15, flocculation factors not exceeding 2.5 and without colloidal gel, should prove satisfactory for thin bituminous surfaces in semiarid or well-drained locations; and (3) the better grade materials, even with a considerable amount of gel, may prove satisfactory as bases for the thicker bituminous surfaces.

SUMMARY

The information available relative to the use of caliche suggests the following conclusions:

1. The stability of caliche base courses for bituminous surfacing depends upon the quality and quantity of the fine binder material (passing the no. 40 sieve) contained in the total volume of material in place.

2. The quality of the binder depends on the geologic origin of the material. The quality can be determined by the standard physical soil tests developed by the Bureau of Public Roads. Study of soil constants derived by subjecting caliches which have given various degrees of road service to this standard series of tests makes possible the establishing of suitable limiting test values.

The quantity of fine soil binder (material passing no. 40 sieve) depends on the nature of the caliche deposit and on the mechanical appliances and methods used in excavating and handling.

3. The hard and semihard caliches are the best materials since they are most likely to contain a desirable quantity and quality of fine binder material.

4. Flourlike or very fine caliches may be used under favorable conditions. However, they generally contain an excessive amount of very fine clay and colloidal material. Such fine material will bind and set when properly manipulated, but the completed road has very high capillary action. Material of this kind should be thoroughly investigated before being used.

5. In regions of sparse rainfall, freedom from frost or snow, and good surface drainage, caliches with high colloidal content, as evidenced by high liquid limits, high plasticity indexes and colloidal gels, may be successfully used to carry light traffic without surface covering. This type of caliche will prove unsatisfactory if a surface covering, which prevents evaporation of capillary moisture, is placed on top of it or if it is placed without providing good drainage.

6. The minimum depth of compacted base course that will give good service, as deduced from records of roads that have been built for 5 or more years, is 8 inches.

7. Base courses in excess of 4 inches compacted depth will give better service if built in two courses. The base course material should be thoroughly compacted from the subgrade upward.

TRAFFIC ON STATE AND COUNTY ROADS OF INDIANA

A DIGEST OF A REPORT BY THE STATE HIGHWAY COMMISSION OF INDIANA [1]

THE present State highway system has been developed since 1920 with funds derived principally from automobile license fees, a gasoline tax, and Federal aid. The county system, the intensive development of which began with the enactment of the State's famous "Three Mile Gravel Road Law" in 1905, was paid for almost entirely with the proceeds of county and township bond issues. The issuance of State bonds is prohibited in the Indiana constitution. There are 2.14 miles of road in the State for each square mile of area, a figure exceeded only in Massachusetts and Connecticut. The mileage of surfaced roads is greater than that of any other State, there being a total of 59,085, of which 8,450 are dustless, including 5,536 miles of pavement. There are 50,635 miles of untreated gravel and waterbound macadam. Most of the pavement is on the State system. Table 1 gives a detailed summary of the various types of surfaces on the State highway system.

The unusual facilities for traveling throughout the year provided by the extensive county road system result in a narrower range of seasonal changes in traffic density than is found in other parts of the Middle West. The topography of the State is faily uniform, there being no mountains and only limited areas of marsh lands where construction is difficult. Indianapolis, with a population of about 400,000 is the largest city. Farming and manufacturing are about of equal importance in the State's economic life. The 1930 population was 3,238,503 of which 55.5 percent was classified as urban and 44.5 percent as rural.

TABLE 1.—*Miles of different types of surfaces on the State highway system, 1932*

Type of surface	Miles	Accumulated total, miles
Brick	106.96	106.96
Cement concrete	3,356.25	3,463.21
Rock asphalt	360.60	3,823.81
Bituminous concrete	52.17	3,875.98
Bituminous macadam	209.84	4,085.82
Surface-treated waterbound macadam	46.26	4,132.08
Bituminous retread	304.87	4,436.95
Bituminous mulch top	437.73	4,874.68
Road-oil mat top	1,766.16	6,640.84
Oil-treated surface	103.48	6,744.32
Stone	507.52	7,251.84
Gravel	863.63	8,115.47
Earth	28.09	8,143.56
Torn up for construction	197.35	8,340.91
Miscellaneous	81.72	8,422.63

SURVEY MADE ACCORDING TO ACCEPTED METHODS

The survey was undertaken to obtain information concerning the volume and kind of traffic on the various classes of highways as a basis for properly classifying highways and controlling expenditures upon them.

The methods of the survey were in accordance with principles which have been developed in a number of State-wide surveys and which are accepted as yielding satisfactory results. Traffic counts were made at 1,016 stations on the State system and data were collected at 525 points on county roads in 21 selected townships in 11 counties representing different conditions throughout the State. For certain classes of data intensive studies were made at a number of representative points and factors determined which were applied to other points of like character. The survey covered a 1-year period beginning in May 1932.

HEAVIEST TRAFFIC FOUND ON U. S. ROUTES

The 8,423 miles of State roads covered by the report do not include the 451 miles of State routes in cities with a population over 3,500 which were not maintained by the State. The Federal-aid highways included in the State system aggregated 4,923 miles.

During the year of the survey there was a motor vehicle movement on the State highways of approximately 6,890,200 vehicle-miles per day. On the county roads the figure was 3,483,953. The relative use of the Federal-aid systems and the United States routes is shown in table 2.

The daily volume of traffic on different parts of the State system varied widely. The number of motor vehicles per average 24-hour day ranged from 18,881 at the junction of routes U S 41 and U S 12 and U S 20 near Chicago, Ill., to a minimum of less than 100 vehicles on some unimproved sections recently added to the system. The average for the entire 8,423 miles was 818 vehicles per day. On county roads the average was 50.6 and the range was between a maximum of 3,943 and a minimum of 2.2.

TABLE 2.—*Average daily traffic on different route classifications of the State highway system*

	Highway mileage	Percent of State highway system	Average daily vehicle-miles	Percent of total vehicle-miles
Primary Federal-aid system	1,830	21.7	3,149,652	45.7
Secondary Federal-aid system	3,093	36.7	2,305,816	33.5
Other State roads	3,500	41.6	1,434,732	20.8
Total State system	8,423	100.0	6,890,200	100.0
US routes	1,933	22.9	3,194,545	46.5

The largest volume of traffic of both passenger cars and trucks is found in the areas adjacent to large centers of urban population and on the main traffic routes. The picture of the traffic flow in the Indianapolis area (as shown by maps accompanying the full report) is a striking example of the urban influence. The flow on all the roads increases as the city is approached. The density lines, on the maps, for U S 40 between Indianapolis and Terre Haute and for U S 52 between Indianapolis and Lafayette show the characteristic maximum on these sections near the urban areas and the minimum midway between the cities.

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[1] The work was executed under the direction of F. A. Henning and W. F. Milner, engineers, and L. E. Freeman, statistician, for the State Highway Commission. The advice and assistance of the United States Bureau of Public Roads was had in planning the survey and supervision was furnished in part by the bureau in collecting field data. The complete report has been published by the State Highway Commission of Indiana.

The most striking example of the combination of the influence of urban traffic and through traffic is in the Calumet region and on U S routes 12 and 50 skirting Lake Michigan. The heavy traffic in this section is the result of a large population within the area itself, its proximity to Chicago, and the junction of several important through routes. The 28 miles of U S 12 outside of cities carries an average daily traffic of 4,509. From Gary to Elkhart, a distance of 63 miles, there is an average flow of 3,061 vehicles per day. The principal through routes, in general, are those designated as U S highways, of which the most important are U S 12, 20, 30, 31, 40, 41, and 52.

The mileage of State highways carrying various densities of total traffic and of truck traffic is shown in figures 1 and 2.

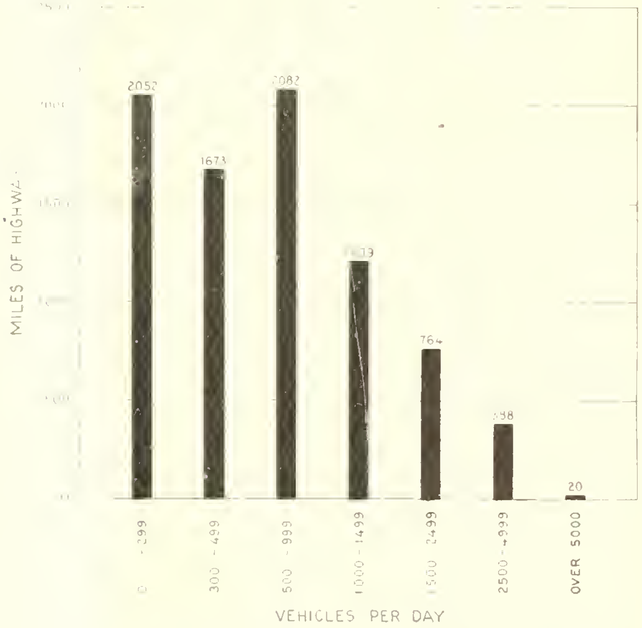

FIGURE 1.—STATE HIGHWAY MILEAGE CLASSIFICATION ACCORDING TO TRAFFIC DENSITY.

AUGUST FOUND TO BE MONTH OF HEAVIEST TRAFFIC

The seasonal variation in traffic is shown in figure 3, which is based on counts at 102 control stations. The bars represent the average traffic during each month as a percentage of the average monthly total traffic. Passenger-car traffic shows a greater variation than truck traffic. Maximum passenger-car traffic was in August and the minimum in March, with a ratio between the two of 1.56. For trucks the high and low months were August and February, with a ratio between them of 1.20.

Figure 4 shows the variation in traffic on different days of the week. Volumes of traffic are expressed as percentages of total traffic on the average week day (average for Monday to Friday, inclusive). Figures 3 and 4 are based on traffic on State highways only. It was found that the increase in traffic on Sunday was greater on local roads than on main routes, probably because of the desire of some pleasure drivers to avoid heavy traffic. Table 3 shows variations between week-day traffic and Saturday and Sunday traffic.

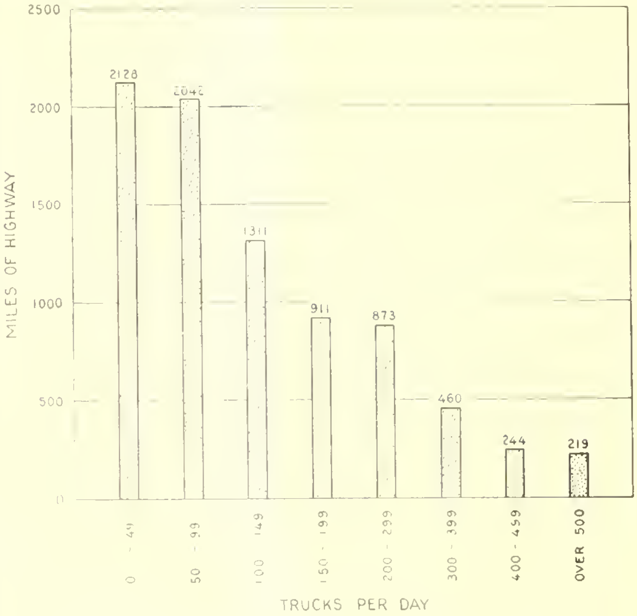

FIGURE 2.—STATE HIGHWAY MILEAGE CLASSIFICATION ACCORDING TO TRUCK DENSITY.

TABLE 3.—*Average Saturday and Sunday traffic as percentages of average week-day traffic*

	Average week-day flow	Saturday flow	Sunday flow
	Percent	*Percent*	*Percent*
Passenger cars	100	121	167
Trucks	100	81	41
Total	100	113	142

HEAVY TRUCK TRAFFIC CONFINED LARGELY TO PRINCIPAL ROUTES

Motor-truck traffic is 16.9 percent of the total traffic on State highways and 16.3 percent of the total on county roads. In the density counts busses were counted as trucks. However, early in the survey, a check was made on the relative number of busses to trucks and to total vehicles. This count showed that the bus flow was less than 1 percent of the total flow and approximately 4 percent of the truck flow.

It is highly significant that the percentage of truck traffic in Indiana is practically the same on State and county roads and still more significant that the percentage of heavy trucks on county roads, as determined by inspection, is approximately half that of heavy trucks on State roads. It was found during the summer of 1933 that 47 percent of the trucks passing the survey stations on State roads during daylight hours were either equipped with dual tires or were obviously large and heavy. This figure includes busses. On county roads the proportion of similar heavy vehicles was 26 percent. Dual tire equipment is principally used on vehicles which may be roughly classified as heavy. No classification by tonnage was attempted.

The average daily traffic flow map published in the full report shows that the number of miles of State roads that averaged over 200 trucks per day are comparatively few. In figure 2 the mileage of the State highway system is classified according to several truck-density classes. The number of trucks per average 24-hour day varied from 3,790 at the junction of routes U S 41 and U S 12 and 20 northwest of Whiting to less

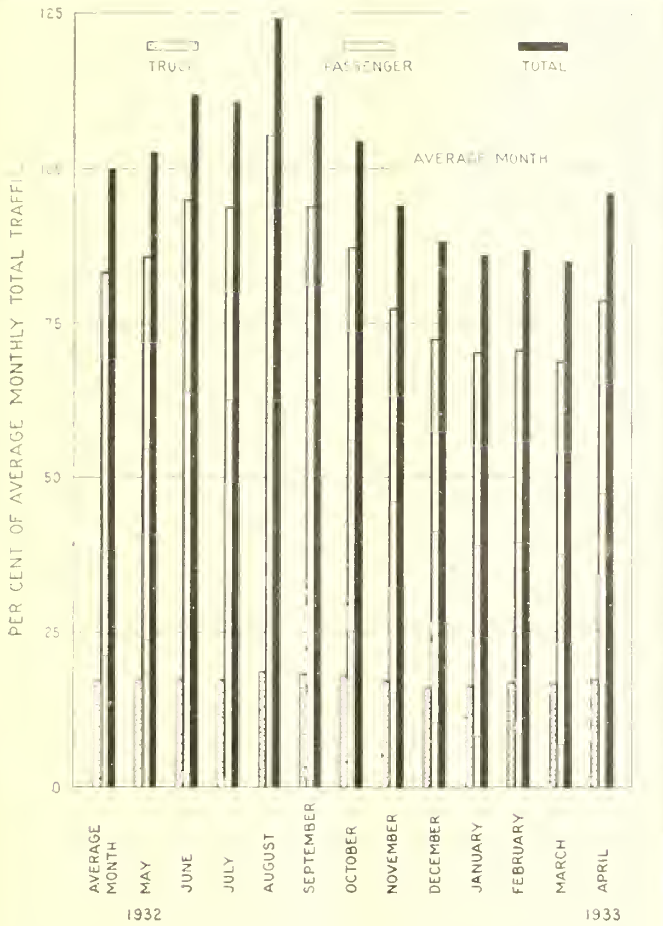

FIGURE 3.—DAILY VARIATION OF TRAFFIC ON STATE HIGHWAYS. TOTAL TRAFFIC ON AVERAGE WEEK DAY (MONDAY TO FRIDAY) IS TAKEN AS 100 PERCENT.

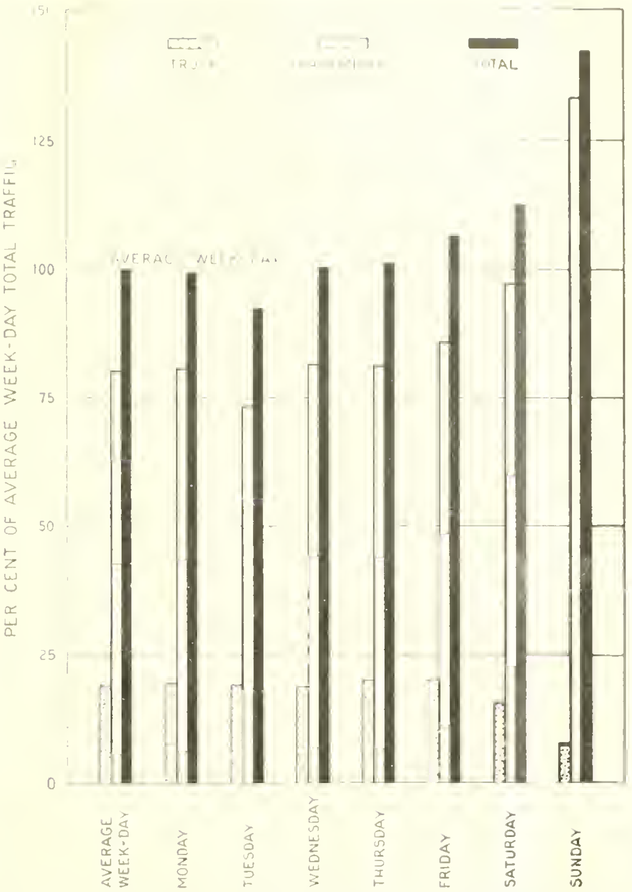

FIGURE 4.—MONTHLY VARIATION OF TRAFFIC ON STATE HIGHWAYS.

than 10 on some of the unimproved sections of the State system. On the county roads the maximum on the average day was 726 and the minimum none.

Table 4 gives the average truck flow on the principal truck routes. The decrease in this traffic on Saturdays and Sundays brings the average flow below the flow on a week day.

TABLE 4.—*Average daily truck flow on the principal truck routes*

Route	Length in miles	Average trucks per day
U S 12—Michigan Line to Illinois Line	28	996
U S 40—Indianapolis to Illinois Line	68	775
U S 40—Indianapolis to Ohio Line	61	415
U S 31—Michigan Line to Louisville	241	356
U S 20—Gary to Elkhart	63	473
U S 20—Elkhart to Ohio Line	60	220
U S 52 and U S 41—Indianapolis to Hammond	151	384
U S 41—Terre Haute to Ohio River	193	327
67-9-U S 24—Indianapolis to Fort Wayne	102	324
U S 30—Illinois Line to Ohio Line	143	255

TRAFFIC ON STATE HIGHWAYS DIFFERED GREATLY FROM THAT ON COUNTY ROADS

Upon analysis of field data it was found that traffic characteristics in Lake County, in the Chicago metropolitan area, differed so widely, in many respects, from those in the other 10 counties that a separate study of them would be required. Tables 5 and 6 show the major characteristics developed for the State as a whole and for Lake County alone. The various items are grouped for convenient comparison and each group represents 100 percent of the traffic. Direct comparison of State road and county road traffic can be made easily. In table 6 for Lake County the first column shows data relative to the State highways; the second, county roads in the northern portion of the county which lies within the Chicago metropolitan area; the third, the entire county road system. Many of the roads in North and Calumet townships are really city streets under the jurisdiction of county authorities. They carry a large volume of traffic and more elaborate studies than those undertaken in this survey will be required to give an adequate picture of them.

All comparisons in the second, seventh, eighth, and ninth groups in both tables are based on 24-hour traffic flow, but the remainder are based on the flow in the daylight period, during which observations were taken and for which no night factors were available. Survey figures show that foreign traffic maintained its percentage with reasonable uniformity throughout the night and indicate that the percentage of city-owned vehicles was greater on the State highways at night and less on county roads, and it may be worth while to bear this in mind in considering the 12-hour characteristics shown in the table. Seasonal variations in the characteristics listed were not great, except in resort areas and on roads near recreation centers and in items which constituted very small percentages of the total traffic.

It is apparent from the figures in table 5 that the State road system has distinctly different traffic characteristics from those found on the county-road system.

Table 5.—Composition of traffic—all roads

	Vehicle-miles		
	Percent on State roads	Percent on county roads	Percent on combined systems
1. Indiana owned vehicles	82.5	96.6	87.2
All other vehicles	17.5	3.4	12.8
Total	100.0	100.0	100.0
2. Passenger cars	83.1	83.7	83.3
Trucks	16.2	16.1	16.2
Busses	.7	.2	.5
Total	100.0	100.0	100.0
3. City vehicles	62.5	33.4	52.8
Farm vehicles	18.4	43.7	26.8
Village vehicles	19.1	22.9	20.4
Total	100.0	100.0	100.0
4. Vehicles traveling to or from points in the township	33.0	71.3	45.8
Vehicles traveling to or from points in the county outside the township	36.7	22.5	31.9
Vehicles traveling to or from points in the State outside the county	22.5	6.0	17.0
Vehicles traveling between points in other States (trans-State)	7.8	.2	5.3
Total	100.0	100.0	100.0
5. Vehicles traveling from city to city	43.5	12.5	33.2
Vehicles traveling from city to country	20.3	17.1	19.2
Vehicles traveling from country to city	19.3	14.7	17.8
Vehicles traveling between points in the country	16.9	55.7	29.8
Total	100.0	100.0	100.0
6. Vehicles traveling within the State (intra-State)	77.9	96.9	84.2
Vehicles traveling between points in Indiana and points in other States (inter-State)	14.3	2.9	10.5
Vehicles crossing the State (trans-State)	7.8	.2	5.3
Total	100.0	100.0	100.0
7. Indiana passenger cars	67.2	80.6	71.7
Foreign passenger cars	15.9	3.1	11.6
Indiana trucks	14.6	15.8	15.0
Foreign trucks	1.6	.3	1.2
Indiana busses	.7	.2	.5
Foreign busses			
Total	100.0	100.0	100.0
8. Passengers cars owned in the county	37.9	60.8	45.6
Passenger cars owned in the State, outside the county	29.3	19.8	26.1
Passenger cars owned in other States or countries	15.9	3.1	11.6
Trucks owned in the county	7.5	11.4	8.8
Trucks owned in the State, outside the county	7.1	4.4	6.2
Trucks owned in other States or countries	1.6	.3	1.2
Busses owned in the county	.3	.1	.2
Busses owned in the State, outside the county	.4	.1	.3
Busses owned in other States or countries			
Total	100.0	100.0	100.0
9. County-owned vehicles	45.7	72.3	54.6
State-owned vehicles	36.8	24.3	32.6
Foreign vehicles	17.5	3.4	12.8
Total	100.0	100.0	100.0

Table 6.—Composition of traffic—Lake County roads

	Vehicle-miles		
	Percent on State roads	Percent on county roads [1]	Percent on county roads [2]
1. Indiana owned vehicles	53.3	85.7	86.8
All other vehicles	46.7	14.3	13.2
Total	100.0	100.0	100.0
2. Passenger cars	85.0	86.0	85.9
Trucks	14.0	12.6	12.9
Busses	1.0	1.4	1.2
Total	100.0	100.0	100.0
3. City vehicles	85.9	89.2	83.9
Farm vehicles	5.6	3.0	6.4
Village vehicles	8.5	7.8	9.7
Total	100.0	100.0	100.0
4. Vehicles traveling to or from points in the township	31.0	84.4	82.7
Vehicles traveling to or from points in the county outside the township	23.9	10.9	12.2
Vehicles traveling to or from points in the State outside the county	28.4	2.7	3.3
Vehicles traveling between points in other States (trans-State)	16.7	2.0	1.8
Total	100.0	100.0	100.0
5. Vehicles traveling from city to city	72.8	79.7	72.3
Vehicles traveling from city to country	12.8	9.2	10.7
Vehicles traveling from country to city	8.9	7.5	8.7
Vehicles traveling between points in the country	5.5	3.6	8.3
Total	100.0	100.0	100.0
6. Vehicles traveling within the State (intra-State)	36.6	83.4	85.0
Vehicles traveling between points in Indiana and points in other States (inter-State)	46.7	14.6	13.2
Vehicles crossing the State (trans-State)	16.7	2.0	1.8
Total	100.0	100.0	100.0
7. Indiana passenger cars	42.9	73.7	74.5
Foreign passenger cars	42.1	12.3	11.4
Indiana trucks	9.6	10.6	11.1
Foreign trucks	4.4	2.0	1.8
Indiana busses	.8	1.4	1.2
Foreign busses	.2		
Total	100.0	100.0	100.0
8. Passenger cars owned in the county	32.0	70.6	68.2
Passenger cars owned in the State, outside the county	10.9	3.1	6.3
Passenger cars owned in other States or countries	42.1	12.3	11.4
Trucks owned in the county	5.9	9.6	9.5
Trucks owned in the State, outside the county	3.7	1.0	1.6
Trucks owned in other States or countries	4.4	2.0	1.8
Busses owned in the county	.4	1.3	1.1
Busses owned in the State, outside the county	.4	.1	.1
Busses owned in other States or countries	.2		
Total	100.0	100.0	100.0
9. County-owned vehicles	38.3	81.5	78.8
State-owned vehicles	15.0	4.2	8.0
Foreign vehicles	46.7	14.3	13.2
Total	100.0	100.0	100.0

[1] In Calumet and north townships only.
[2] In all townships.

The figures for the different sections of the individual roads included in the averages shown in the table indicate that extreme variations from these averages may be found on a single road. For instance, most of the characteristics found on U S 31 in Marion County are quite different from those in Scott County. Centers of population, proximity to the State border or location in a highly developed resort area will cause changes in the composition of the traffic which will make the figures for certain sections of almost any State road either greater or less than similar figures for the average county road. Likewise, many of the county road characteristics shown in the table vary widely between the different counties in which the survey was conducted, although the percentages of foreign vehicles and of trucks are fairly uniform. Individual county roads can be compared with the State road figures shown only when full consideration is given to every detail of their geographical locations. In making such comparisons it must be remembered that the average State road carries 16 times as much traffic as the average county road, and that even though a certain county road shows a higher percentage of foreign or nonlocal traffic than the average State road the volume of such traffic may be practically negligible. The possibility of a material increase in these two items following the inclusion of a road in the State system must be studied.

The relative use of the roads by local and nonlocal vehicles is perhaps the most important comparison of the various traffic elements that can be made from the tables. In this survey if a vehicle either began or ended its trip in a certain place it was counted as local to that place. The first item in group 4 of either table is local traffic in the average township. The second item is traffic found crossing the township but local to the county in which the township is located. The sum of items 1 and 2 is the amount of traffic local to the entire county. The third item is traffic crossing both township and county coming from or going to points within the State and is called State traffic. Vehicles in the fourth item cross the State from border to border, passing through the county and the township. Thus the entire average vehicular movement is divided into "township", "county", "State", and "trans-State" traffic. The figures in table 5 indicate that the State highways carry an average of 33 percent township traffic, while the county roads carry 71.3 percent. Combined township and county traffic on the State highways is 69.7 percent of the total and on county roads 93.8 percent. Other comparisons are easily made from the tables themselves. The figures are averages for the entire State and vary materially between urban and rural areas.

By combining township and county figures in the fourth group and comparing them with the combined figures for county-owned cars in the last group we find that about 46 percent of the traffic on the State roads originates in the local county while about 24 percent additional has its destination there, having come from somewhere else. These same figures for the county roads are approximately 72 percent and 22 percent. The remainder of the traffic in each case moved entirely across the county. In this method of comparison, location of ownership denotes origin. In other words, the "origin or destination" method indicates that about 70 percent of the State highway traffic and 94 percent of the county road traffic is local to the county in which a road lies, while the "origin only" method indicates 46 percent and 72 percent, respectively, for these two items. "Origin only" figures for the townships are not available.

In this survey municipalities with 2,500 or more population were classed as cities. Automobile license registration figures in 1932 showed that 54.3 percent of all vehicles were owned in cities, 26.6 percent on farms, and 19.1 percent in villages or towns. Traffic on State roads was found to consist of 62.5 percent city vehicles, 18.4 percent farm, and 19.1 percent village. On the county roads, farm and village vehicles aggregated 66.6 percent. On the combined systems city vehicles constituted 52.8 percent of the traffic. Vehicles traveling from city to city, and city to country accounted for 63.8 percent of the State highway traffic, which is almost the same as the percentage of city-owned vehicles found on these roads. The movement between points in the country and from the country to the city on the county roads was 70.4 percent, which may be compared to the 66.6 percent of farm and village vehicles found on these roads. Figures in the table showing a slightly greater movement from city to country than in the opposite direction indicate that some of the heavy pleasure traffic starting from the cities during daylight hours did not return until after the counting stations were closed for the night or that they returned by different routes.

Trucks and busses were the only commercial vehicles segregated in the survey. Under the Indiana law busses used exclusively for carrying children to and from school are classed as trucks and carry truck license plates. While there are approximately 7,000 such vehicles in use they are very light, frequently mounted on passenger-car chassis, and travel an average of only 3,200 miles a year each.

The average mile of the State highway system carried 818 vehicles of all types a day; 680 of these were passenger cars, 132 were trucks and 6 were busses. On the county system these figures were 42.4, 8.1, and 0.1, making a total of 50.6 vehicles per day.

Bus registrations in the State amounted to only 878, and these few together with those registered in other States accounted for the flow shown above. On the State roads approximately 1 bus in each 7 is foreign. Out of each 13 trucks 1 is foreign, and 1 in each group of 7 passenger cars is of foreign registration. Foreign traffic on the county roads is very light (3.4 percent). Although there is hardly any bus traffic on the county roads it is interesting to note that the ratio of passenger cars to trucks and busses is practically the same on State and county roads. Foreign trucks are found to furnish 1.5 percent of the total State traffic on State roads, while foreign busses account for less than one-tenth of 1 percent. The total truck traffic is 16.9 percent. In other words, one-eleventh of the truck traffic, including busses, is of foreign registration.

COUNTY ROADS DO NOT EARN MAINTENANCE COSTS

Between May 1, 1932, and April 30, 1933, the net revenue from the 4-cent gasoline tax earned on all rural roads was $10,656,867. Of this total 66.5 percent, or $7,081,766, was earned on State roads and 33.5 percent, or $3,575,101, on county roads. These figures are based on an estimated gasoline consumption by passenger cars of 15 miles per gallon and 11¼ miles per gallon by trucks, which are the figures used by the Bureau of Public Roads in its report on the Survey of the Eleven Western States. No evidence has been produced since the publication of that report to justify a revision of these figures, although all available pertinent data have been studied. Some interesting light is thrown on this

(Continued on p. 250)

TABLE 7.—*Relative gasoline tax earnings on the State road and county road systems during the period of the survey, May 1, 1932, to Apr. 30, 1933*

		Passenger		Truck		Total		
			Percent of total		Percent of total		Percent of total	Percent of grand total
State roads	Daily vehicle-miles	5,727,296	83.1	1,162,904	16.9	6,890,200	100	......
	Yearly earnings	$5,574,568	78.7	$1,509,217	21.3	$7,081,766	100	66.5
County roads	Daily vehicle-miles	2,916,676	83.7	567,277	16.3	3,483,953	100	......
	Yearly earnings	$2,838,888	79.4	$736,213	20.6	$3,575,101	100	33.5
	Grand total—earnings	......		......		$10,656,867	......	100.0

EFFECT OF TEMPERATURE AND MOISTURE CONTENT ON THE FLEXURAL STRENGTH OF PORTLAND CEMENT MORTAR

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by D. O. WOOLF, Associate Materials Engineer, and K. F. SHIPPEY, Junior Highway Engineer

IN A REPORT on the effect of steel reinforcement in concrete pavements which was presented at the 1931 meeting of the Highway Research Board,[1] several theoretical considerations of the effect of change in moisture content and temperature on the flexural strength of concrete were advanced. It was stated that while both a lowering of temperature and a decrease in moisture content will cause a concrete slab to shorten in linear dimensions, these two effects may have opposite reactions on the flexural strength. When shrinkage occurs due to loss of moisture, the cement is placed under compression by the surface tension of the "solidified" water, and the modulus of rupture will be increased. Filling the pores of the mortar with water subsequent to drying reduces the capillary pressure to zero and causes the mortar to swell and the flexural strength to diminish. On the other hand, a decrease in temperature of rigid concrete causes molecular consolidation, the inert particles become smaller in diameter and the glue bands of the cementing material tend to shorten. This causes the linear dimensions of the slab to diminish and the glue bands to become stretched in effect and thus be placed in tension. This, in theory, should reduce the modulus of rupture.

This theoretical conception of the effect of temperature on the modulus of rupture was supported by the results of a series of tests of concrete made under field conditions. Since accurate control of temperature and moisture is quite difficult in the field, it was decided to make a series of tests under laboratory conditions to check the effect of temperature and moisture on the strength of mortar.

Several years ago a short series of tests to determine the effect of moisture content on the strength of mortar was made, using tension, compression and flexure specimens.[2] After 6 months' curing in water, a portion of each set of specimens was dried in warm air for 2 days and then tested. The remainder of the specimens were tested wet. The following results were found:

Mortar strength, pounds per square inch

Test	Wet	Air dry
Tension	530	380
Compression	6, 215	7, 145
Flexure	675	445

These results do not agree with the theories advanced. However, it is now believed that lack of agreement is the result of the air-dried specimens not being thoroughly dry and that when tested they still contained an appreciable quantity of water. Subsequent tests have indicated the correctness of this conclusion.

Following these tests a set of seven 2- by 3- by 18-inch mortar beams of 1:3 mix with Potomac River sand was tested at an age of 2 years to determine the effect of moisture content on the flexural strength. After each beam had been tested in a saturated condition, the beams were oven dried at 105° C. to constant weight and tested dry. As shown in table 1, the wet beams developed a flexural strength averaging 750 pounds per square inch. The average strength of the dry beams was 1,065 pounds per square inch, or 142 percent of the strength of the wet beams. These tests demonstrated that the moisture content had an appreciable effect on the flexural strength.

To determine the effect of both temperature and moisture, three series of mortar beams were prepared, using a 1:2 mix by weight of stock cement and Potomac River sand with a water-cement ratio of 0.68 by volume. Each series consisted of 6 beams 2 by 3 by 16 inches, and 6 beams 2 by 3 by 12 inches. Two other beams of the same proportions and consistency were cast with thermocouples and a thermometer placed in them. It was the intention to use these beams as temperature control specimens for the test beams. After one day in moist air, the beams were removed from the molds and stored in water at a temperature of 70° F. At an age of 28 days, half of the beams were dried in an oven at a temperature of 150°±5° F. for a period of 7 days, in which time they attained a constant weight.[3] All beams were tested at an age of 35 days.

TABLE 1.—*Moduli of rupture of mortar beams tested in flexure at age of approximately 2 years with specimens at room temperature*

Beam	Beams wet			Beams oven-dried to constant weight			Increase in strength
	1	2	Average	1	2	Average	
	Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Percent*
1	827		827	1, 140	1, 101	1, 120	136
2	702		702	1, 082	999	1, 040	148
3	685		685	1, 136	1, 155	1, 146	167
4	664		664	1, 123		1, 123	169
5	853		853	1, 026		1, 026	120
6	762		762	988		988	130
7	746	756	751	1, 009		1, 009	134
Average			750			1, 065	142

Prior to the tests, investigations of the rate of heating or cooling of mortar beams were made to determine the time required to bring a test beam to the desired temperature. For this purpose, a surplus beam of unknown age was fitted with a thermocouple and thermometer. The beam was subjected to all the heating and cooling treatments proposed for use in the test, and time-temperature records obtained. It was found in this preliminary treatment that the thermometer reading usually showed a lag of 2° or 3° F. behind that obtained with the thermocouple. Some difficulty was experienced, however, in making thermocouple readings because of vibration of the galvanometer mirror. While the thermocouple was believed to give more accurate determinations of temperature, it was decided to use thermometer readings in the proposed tests.

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[1] Functions of Steel Reinforcement in Concrete Pavements and Pavement Bases, by C. A. Hogentogler, E. A. Willis, and F. A. Robeson, Proceedings, Highway Research Board, vol. 11, pt. 1.

[2] Effect of Moisture Content on the Strength of Cement Mortar Specimens, by D. O. Woolf and Baxter Smith, PUBLIC ROADS, August 1929.

[3] Loss of 1 gram (0.03 percent) or less in 24 hours' heating.

FIRST SERIES OF TESTS INCONCLUSIVE

Tests were made of the flexural strength of beams at temperatures of 40°, 70°, and 100° F., in both oven-dried and saturated conditions. One long and one short beam were tested on each of 3 days for each of the 6 conditions of temperature and moisture. In most cases, 15 breaks were made under each test condition. Some specimens failed by shear at the ends because of uneven surfaces, and such breaks were discarded. After each test, the dimensions of the beam at the plane of failure and the length of the lever arm to the plane of failure were measured, and the modulus of rupture computed. The cantilever machine used has been described in Public Roads for May 1928. A 36-inch lever arm was used rather than the 18-inch arm used in the first work with the machine.

In the preliminary series of time-temperature tests, it was found that it was necessary to allow for a change of 10° F. in the temperature of the beam while in the testing machine, in making tests at 40° and 100° F. The beams for the low-temperature tests were cooled to freezing temperature before being placed in the testing machine, a bath of melting ice being used for the wet specimens, and the dry specimens being cooled by electric refrigeration. Wet specimens for testing at 100° F. were heated in water to 110° F. before being placed in the testing machine. Dry specimens for testing at 100° F. were oven heated to 150° F. and cooled in room air to 110° F. before being placed in the machine. The wet beams tested at 70° F. were taken direct from the laboratory storage water, while the dry beams were cooled from 150° to 70° F. in room air before testing.

The temperature of the test specimen at the moment of failure was obtained by subjecting the thermometer equipped control beam to the same temperature treatment as was given the test specimen. When the test beam was placed in the testing machine, the control beam was placed beside it, and the test was made when the control beam reached the desired temperature.

Upon the completion of this series of tests it was observed that the individual test results at a given temperature were not always concordant, especially in the case of the beams tested in a dry condition.

An inspection of the average results also showed a much smaller difference in strength, due to moisture condition at time of test, than had been indicated by the 2-year tests previously noted. It was felt that this might be due to the proportionately greater amount of water-curing given the wet beams (35 days as compared with 28 days for the beams tested dry). This would introduce an error which might be corrected, in part, by increasing the wet-storage period. It was therefore decided to repeat the test, using the same materials, proportions, and water-cement ratio but to give all beams a preliminary curing of 90 days in water instead of 28 days as in the former series. In this second series of tests, six 2- by 3- by 16-inch beams were prepared on each of 12 days and stored for 90 days. Three of each set of six beams prepared on 1 day were then removed from storage and dried to constant weight at a temperature of 150° ± 5° F. The remaining specimens were continued in water storage. At an age of 103 days both wet and dry beams were tested for flexural strength at temperatures of 40°, 70°, and 100° F., using the same methods as given above.

SECOND SERIES OF TESTS SHOWS IMPORTANCE OF CONTROL OF MOISTURE AND TEMPERATURE IN TESTING

The results of the two series of tests are given in tables 2 and 3, and in figure 1. In all cases, increase in temperature resulted in lowering the flexural strength of the mortar. This is more marked in the tests of the wet beams, and here a greater reduction in strength was found with increase in temperature from 70° to 100° F. than from 40° to 70° F. At an age of 35 days, the dry specimens tested at a temperature of 40° F. developed only 94 percent of the strength of the wet beams, but at 100° F. the dry beams had a strength of 118 percent of that of the wet beams. At 70° F. the dry and wet beams had practically the same strength.

At an age of 103 days, the strengths of the dry beams greatly exceeded the strengths of the wet beams at all temperatures. At 40° F. the dry beams were 144 percent stronger; at 70° F., 145 percent stronger; and at 100° F., 195 percent stronger. It will be recalled that in the tests made at 2 years, the flexural strengths of the dry beams tested at 70° F. averaged 142 percent of the strengths of the wet beams. It is apparent that the time of curing has a considerable effect on the ratio of flexural strength of wet and dry beams tested at the age of 35 days. In this case, the wet beams were cured in water for 35 days but the dry specimens had only 28 days' water-curing, followed by heating. This treatment probably affected the strengths of the dry specimens adversely.

It is interesting to note that, insofar as the effect of temperatures of specimens at time of test is concerned, these tests verify the results obtained several years ago by Parkinson, Finch, and Hoff, of the University of Texas[4] which indicated quite definitely that the

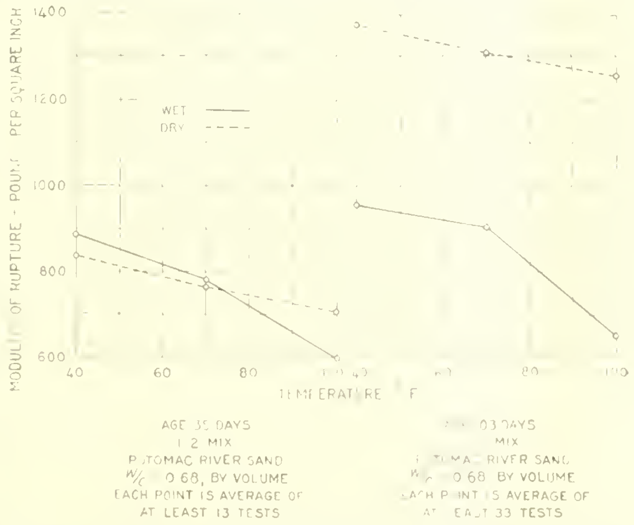

Figure 1.—Effect of Temperature and Moisture Conditions at Time of Test on Flexural Strength of Portland Cement Mortar.

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[4] Relation Between Strength of Portland Cement Mortar and Its Temperature at Time of Test, University of Texas Bulletin no. 2825, July 1, 1928.

Table 2.—*Moduli of rupture of mortar beams tested in flexure at age of 35 days and at various temperatures at time of test*

Beams, dry			Beams, wet		
40° F.	70° F.	100° F.	40° F.	70° F.	100° F
Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
726	672	590	897	788	575
862	740	614	852	785	689
828	705	607	900	765	635
816	744	570	797	784	552
731	734	811	817	777	622
965	677	787	838	797	520
749	771	678	850	827	565
829	891	900	989	676	586
849	877	928	811	802	655
788	840	691	929	818	585
851	750	750	966	820	599
836	847	595	986	741	606
890	710	654	886	770	571
994	621			758	601
	918			774	624
Av. 837	767	706	886	778	599

Table 3.—*Moduli of rupture of mortar beams tested in flexure at age of 103 days and at various temperatures at time of test*

Beams, dry			Beams, wet		
40° F.	70° F.	100° F.	40° F.	70° F.	100° F.
Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per quare inch*	*Pounds per square inch*
1,489	1,294	1,310	994	938	662
1,416	1,399	1,399	1,017	873	599
1,392	1,391	1,310	1,004	940	630
1,365	1,134	1,194	1,020	996	631
1,419	1,041	963	975	861	688
1,237	1,255	1,143	908	935	677
1,223	1,164		932	920	570
1,238			1,036	928	596
1,279	1,122		948	870	
1,364	1,366	1,373	987	924	615
1,337	1,524	1,342	975	978	615
1,428	1,400	1,204	981	876	649
1,458	1,396	1,353	995	935	627
1,389	1,375	1,345	904	860	688
1,460	1,368	1,374	998	933	729
1,469	1,274	1,339	1,023	1,000	708
1,395	1,289	1,206	979	913	639
1,364	1,384	1,330	984	925	717
1,342	1,356	1,300	921	894	623
1,465	1,274	1,265	927	858	654
1,360	1,277	1,304	935	856	596
1,373	1,314	1,254	891	842	636
1,404	1,381	1,257	916	888	689
1,386	1,342	1,268	963	924	649
1,372	1,317	1,293	933	884	624
1,446	1,317	1,246	897	805	632
1,399	1,346	1,230	927	811	612
1,339	1,262	1,268	943	937	701
1,381	1,247	1,161	923	848	618
1,391	1,381	1,221	956	865	657
1,318	1,257	1,277	972	936	594
1,304	1,260	1,152	892	911	664
1,423	1,306	1,199	1,001	911	573
1,404	1,332	1,194	923	883	699
1,429	1,345	1,290	990	915	
1,369	1,339	1,171	858	878	696
Av. 1,379	1,309	1,259	956	901	646

strength of mortar specimens tested in a wet condition is decreased as the temperature at the time of test is increased.

It should be noted that these observations were made on mortars using a single cement and a single sand and with one proportion. It is possible that the use of other materials and proportions might have indicated somewhat different relations.

The following conclusions appear to be warranted by the results obtained in these tests:

1. Increase in temperature of mortar beams at time of test results in a reduction of the flexural strength.
2. The effect of the temperature of a mortar beam at time of test on the flexural strength is more pronounced in the case of beams tested in a wet condition than with oven-dried beams.
3. In these tests, the flexural strength of mortar beams tested in a wet condition appeared to be affected to a greater extent by a change in temperature from 70° to 100° F. than from 40° to 70° F.
4. Mortar beams tested in a dry condition show a uniform reduction in flexural strength with increase in temperature from 40° to 100° F.
5. Mortar beams tested in a dry condition develop higher flexural strength than beams tested in a wet condition provided duplication in curing conditions has been attained.

These tests point to the necessity of closely controlling both the temperature and the moisture condition of concrete specimens for flexure tests at the time of test.

Because of the comparative ease with which saturation of specimen can be insured it is recommended that all flexure tests be made with saturated specimens. In view of the fact that a temperature of 70° F. is commonly used and can be quite conveniently controlled, it is recommended that this temperature plus or minus 5° F. be established as a standard temperature for testing.

TRAFFIC ON ROADS OF INDIANA

(Continued from p. 247)

subject by the results of an analysis of the registration figures in Indiana made during the period of the survey. It was found that 42 percent of all trucks had a capacity of less than 1 ton, 91.8 percent had a capacity of less than 2 tons, and an additional 5.3 percent were rated at less than 3½ tons. Very heavy vehicles with high rates of gasoline consumption constituted only 2.9 percent of the total registration.

Proportioned on the same basis registration fee earnings on the rural roads during the period of the survey amounted to $3,821,306. Of this amount the State roads earned $2,539,841 and the county roads earned $1,281,465.

The net total earnings from the two sources just mentioned were $14,478,173. Table 7 shows the daily vehicle-miles of travel on each system, separated as to trucks and busses, and the relative gasoline-tax earnings in each case. From these figures we find that in gasoline tax and automobile license fees the average State road earns $1.40 annually for each daily vehicle-mile of travel (365 vehicle-miles in a year) and the average county road earns $1.39. On this basis it is evident from figure 1 that a considerable mileage of State roads is not earning maintenance charges, which averaged $411 per mile in 1932, but the average earnings per mile on the State system are $1,145.20. The average earnings on the county system are $70.33 per mile, which indicates that the county system as a whole does not earn its cost of maintenance, which, in 1931, was approximately $187 per mile.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS I.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF NOVEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 4,385,124	$ 2,396,205	$ 35,889	237.6	$ 2,636,193	$ 1,357,286	$ 158,342	171.8	$ 58,042	$ 416,749	29.6	$ 136,220	$ 1,518,940
Arizona	3,878,555	1,338,712	4,307,361	3,718,223		284.2	746,769	96,741	648,668	51.0	4,655	72,904	3.1	58,935	617,140
Arkansas	3,374,167	1,714,000	2,003,051	1,604,863		97.6	1,769,519	1,598,375		76.1	72,616	578,945	23.4	98,314	1,135,055
California	7,912,928	3,713,643	7,164,849	5,384,201		241.8	4,957,185	2,517,283	826,645	85.8		195,800	11.7	11,445	2,691,198
Colorado	3,437,265	2,424,504	3,196,462	3,180,459		141.3	1,875,425	213,641	1,538,075	92.9		183,131	7.0	43,164	703,298
Connecticut	1,404,213	607,500	565,723	565,723		10.7	1,507,276	837,905	498,023	25.5	564	12,499			96,978
Delaware	892,544	461,697	876,080	873,987		18.0	467,709		452,532	10.7				18,557	9,166
Florida	2,519,010	1,330,672	2,817,619	2,088,980		103.4	601,207	339,123	147,473	16.9	58,425	251,540	10.9	32,483	931,658
Georgia	5,045,592	2,556,745	2,926,354	2,903,506		203.3	1,584,204	1,440,059		90.5	296,788	139,839	20.8	405,240	2,416,906
Idaho	2,166,858	1,131,910	2,068,131	1,986,705	14,243	177.9	557,239	150,095	374,630	23.7		67,364	10.6	30,058	675,673
Illinois	4,468,247	3,060,041	1,259,508	1,258,271		26.6	3,266,271	3,058,345	194,944	35.2	151,631	232,610	5.5		2,632,486
Indiana	5,018,921	2,843,478	1,788,127	1,781,926		65.9	2,571,542	2,570,855		69.1	451,103	110,100	17.4	215,037	2,733,378
Iowa	5,027,830	2,217,361	4,636,791	4,456,051		240.5	1,944,999	543,650	1,239,017	146.1		523,480	30.2	28,129	454,864
Kansas	5,044,802	2,558,837	4,923,320	4,772,059	35,977	408.3	1,404,395	211,063	1,037,656	187.0		659,894	92.6	61,680	825,311
Kentucky	3,751,605	1,527,324	3,217,161	3,060,734		227.7	885,248	575,203	192,298	50.2	94,933	254,506	32.0	20,735	1,080,520
Louisiana	2,681,152	1,330,419	1,507,997	1,506,764		60.7	1,873,744	1,141,619	225,474	24.7	12,232	215,695	.7	20,537	933,250
Maine	1,617,560	793,644	1,302,743	1,277,647		43.1	776,514	241,619	524,425	12.7		236,028	7.8	96,294	33,191
Maryland	1,782,263	289,610	527,930	518,282		10.5	1,031,803	925,217	106,586	20.2	204,764	13,660	4.3	134,001	169,363
Massachusetts	1,101,716	1,632,874	1,157,821	868,570		32.5	261,099	157,399		5.2		749,709	9.9	75,747	383,165
Michigan	6,113,389	3,226,284	3,802,535	3,786,680		173.5	3,004,525	2,303,250	652,275	121.0		567,575	21.0	23,459	2,006,434
Minnesota	4,561,011	2,642,244	5,295,204	4,143,865	1,067,676	801.7	1,046,730	383,615	590,115	149.0		439,623	62.5	33,532	524,829
Mississippi	3,489,337	2,301,148	2,514,890	1,348,075		138.3	3,505,643	1,762,606	300,907	176.2	139,940	375,549	38.6	238,716	1,624,692
Missouri	5,237,532	2,778,183	4,431,303	3,904,174		179.8	2,236,040	1,027,297	1,003,292	67.3	293,639	437,066	13.8	12,423	1,337,824
Montana	4,463,849	2,714,208	5,102,182	4,415,927	109,308	384.1	1,445,667	15,129	1,298,099	171.3		606,677	39.2	[illegible]	700,124
Nebraska	3,914,481	1,982,132	4,408,564	3,330,588		306.7	1,960,839	578,887	927,171	114.5		158,335	18.2	5,006	890,676
Nevada	2,909,387	1,350,356	2,717,093	2,669,838		259.1	571,715	133,064	438,651	48.3		347,370	62.2	106,485	564,334
New Hampshire	725,739	484,731	656,678	641,338		10.8	322,315	79,019	228,130	7.7		224,470	4.6	5,382	32,131
New Jersey	3,099,371	951,379	1,694,514	1,674,982		31.8	1,454,171	1,314,704		15.4	97,912	106,716	2.7	11,772	844,664
New Mexico	2,846,648	1,676,769	2,924,494	2,780,565		274.2	1,058,548	18,762	1,039,786	102.5		98,724	7.3	47,322	538,258
New York	10,465,672	2,872,521	8,074,884	7,181,395	11,000	174.9	8,996,468	3,283,803	2,110,200	159.6		139,406	18.3	474	611,915
North Carolina	4,761,147	2,040,068	3,972,434	3,345,600	6,884	529.8	1,464,974	726,891	298,860	148.6	[illegible]	11,441	17.7	417,667	[illegible]
North Dakota	[illegible]	1,469,484	2,977,675	2,588,455	16,672	958.4	435,864	188,435	138,626	109.1	29,897	392,618	215.2	95,436	921,567
Ohio	7,277,758	3,539,255	7,301,586	6,976,134		189.6	627,980	154,648	364,820	12.5		1,788,280	38.3	146,976	1,386,156
Oklahoma	4,608,399	2,342,590	3,433,619	3,378,528		268.2	939,899	933,664		35.7	181,001	1,003,496	60.3	115,207	1,339,094
Oregon	3,053,448	1,548,906	3,254,723	2,961,134		182.2	1,156,077	59,497	981,835	48.1		64,097	.4	32,817	502,974
Pennsylvania	[illegible]	4,554,082	4,287,464	4,176,066	17,389	107.8	4,305,941	2,422,183	1,624,775	59.9	10,865	1,133,576	27.5	82,079	1,778,341
Rhode Island	979,367	464,572	996,030	933,162		20.5	215,718		215,718	6.7	46,205	245,737	4.8		3,117
South Carolina	2,729,583	1,385,477	1,119,787	1,116,913		103.0	1,697,875	1,571,817	109,624	143.0	14,500	312,276	22.4	26,353	[illegible]
South Dakota	3,005,739	1,523,821	2,440,936	2,137,065		407.9	957,342	796,375		133.6	72,299	528,721	164.1		995,101
Tennessee	4,246,309	2,105,453	[illegible]	2,997,623		140.3	1,223,987	969,926	254,061	51.5	216,035	608,058	26.1	62,725	[illegible]
Texas	[illegible]	[illegible]	10,046,798	9,540,155		893.9	[illegible]	1,923,516	156,017	134.3		[illegible]	181.8	124,972	[illegible]
Utah	[illegible]	1,066,345	2,348,442	2,160,784	[illegible]	234.0	951,029	173,572	538,600	83.3		23,242	2.7	[illegible]	[illegible]
Vermont	928,184	466,042	849,889	807,290	[illegible]	[illegible]	336,497	116,745	251,974	17.5		25,648	1.4	4,148	178,348
Virginia	3,706,379	[illegible]	[illegible]	[illegible]		143.0	471,669	291,573	68,207	14.6	26,480	1,093,463	44.7	56,830	[illegible]
Washington	[illegible]	[illegible]	[illegible]	[illegible]		94.8	1,000,038	436,929	563,109	24.2	1,485	225,973	7.1	40,366	[illegible]
West Virginia	[illegible]	1,140,167	[illegible]	[illegible]		61.3	817,613	326,365	474,356	29.9		[illegible]	7.4	[illegible]	[illegible]
Wisconsin	4,615,429	1,865,947	4,443,696	[illegible]	500	[illegible]	617,438	[illegible]	[illegible]	35.9		[illegible]	[illegible]	[illegible]	[illegible]
Wyoming	2,250,663	1,692,907	2,320,877	[illegible]	67,583	468.2	[illegible]	193,976	[illegible]	[illegible]		174,243	[illegible]	[illegible]	[illegible]
District of Columbia															
Hawaii	1,683,956	598,778	254,428	178,070		10.9	1,766,159	1,437,846		28.1	66,000		.7	[illegible]	598,778
TOTALS	185,375,363	94,078,317	153,409,790	137,109,244	1,542,194	10,406.1	78,457,178	41,845,002	23,860,357	3,563.1	2,873,020	18,743,547	1,481.9	3,548,097	49,882,219

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF NOVEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389.928	$ 1,064.961	$ 783.134	$ 783.134	$	19.9	$ 1,388.494	$ 1,388.494	$	41.8	$ 47.630	$ 73.007	4.0	$ 170.670	$ 991.953
Arizona	807.982	305.191	522.097	514.133	6.592	12.7	145.384	105.818	30.635	2.0	129.322	2.709	.2	58.710	265.254
Arkansas	1.889.534	857.025	1.106.233	1.017.847		30.4	783.565	756.485		13.3	115.201	17.857	1.9		839.168
California	4,213.986	2,219.360	3.816.831	3.332.266		45.7	1.145.268	863.848	50.000	7.5		217.500	.3	17.872	1.951.860
Colorado	1.718.633	190.000	1,762.843	1.712.885		35.2	19.122		19.122	1.8		170.878	2.0	5.748	
Connecticut	802.407	426.500	806.490	802.407		10.2	6.892		6.892			155.920	1.2		263.687
Delaware	477.680	230.849	356.021	347.740		6.4	172.485	118.305	54.180	1.5	4.919			6.717	176.669
Florida	1,410.008	665.336	909.627	670.710		10.4	724.947	724.947		8.1	7.721	79.475	2.1	6.629	585.861
Georgia	2,724.620	1.278.373	1,021.094	1.020.089		44.4	813.472	813.472		21.4	448.889		6.3	442.170	1.278.373
Idaho	1,197.829	321.126	838.439	799.742	2.643	19.2	390.046	367.764	22.282	1.6		2.733	.2	30.323	293.468
Illinois	7.692.483	2.515.835	5.159.256	5.111.073		56.1	2,268.824	2.268.824		14.5	185.253	213.466	3.4	127.333	2,302.369
Indiana	4.416.651	2.035.585	1.899.127	1.894.263		45.8	1,909.783	1.909.783		23.6	432.006	13.156	3.9	180.599	2.022.429
Iowa	2.614.472	1.311.000	1.676.770	1.583.614	2.680	49.0	967.446	884.858	38.273	11.1	146.000	169.505	7.5		1,100.542
Kansas	2.522.401	1.279.419	2.025.212	2.005.723	896	36.3	809.403	453.792	210.758	5.3	32.129	199.290	5.1	30.758	868.476
Kentucky	1.927.828	954.578	1,053.632	1,035.277		23.1	814.016	688.899	120.789	9.5	63.000	160.649	4.4	140.653	673.140
Louisiana	1.748.577	744.560	586.072	586.072		13.4	909.501	861.674	21.233	13.7	118.177		2.1	182.653	723.327
Maine	909.878	490.045	804.324	801.222		16.4	38.606	38.606		.4		58.848	.1	70.050	431.197
Maryland	891.132	452.514	296.278	292.128		3.1	1.003.656	190.135		1.4				408.869	452.515
Massachusetts	5.007.199	847.600	1.039.670	998.126		6.6	3.914.353	3.889.377		10.0		194.042	1.6	119.696	653.557
Michigan	3.438.781	1.613.142	2.049.059	2.040.697		34.2	1,803.723	1.391.623	399.600	12.0	6.461	330.600	1.5		882.942
Minnesota	3.719.143	1,421.494	3.127.348	2.954.560	144.685	104.7	489.811	225.210	256.401	12.3		37.531	5.7	539.373	982.877
Mississippi	1.744.669	885.057	524.869	512.409		18.5	671.990	608.966	63.024	24.1	275.321	55.146	7.7	347.973	766.887
Missouri	4.019.501	1.543.435	2.119.202	1.969.238		48.6	1,681.082	1.512.454	144.128	12.6	119.164	325.731	2.7	418.644	1,073.577
Montana	1.115.962	113.092	1.066.829	1.066.829		32.4	66.727	34.716	7.458	4.6	8.796	28.207	3.2	5.621	77.427
Nebraska	1.957.240	991.091	992.042	961.073	19.792	26.6	1.111.514	945.184	166.330	10.7		248.692	4.0	50.983	556.277
Nevada	500.051	100.000	504.552	481.548		8.8						1.000		18.504	99.000
New Hampshire	706.640	242.366	682.527	680.010		15.6	168.358		168.358	3.1		9.220	.3	26.630	64.788
New Jersey	3.190.118	1.809.500	1.560.965	1.486.604		10.6	1.665.825	1.611.692		12.2		399.314	4.2	91.822	1,410.186
New Mexico	1.674.158	529.506	1.286.002	1.286.002		29.8	469.687	286.479	183.208	10.4		60.330	1.7	101.677	285.969
New York	8.255.661	4.203.000	4.777.109	4.594.395		46.4	4.523.356	3.649.256	539.900	21.9		2.048.650	13.0	12.010	1.614.450
North Carolina	2.380.573	1.210.236	1.782.121	1.766.962	13.035	69.1	376.392	335.266	20.407	11.3	186.092	38.257	2.9	92.252	1.138.537
North Dakota	1,451.112	734.741	981.073	979.094		41.0	175.825	175.825		8.6	277.925	139.336	13.9	18.268	595.406
Ohio	4.335.686	2.359.504	4.382.141	3.898.898		54.7	453.230	398.438	23.000	4.8		818.500	12.6	38.349	1.518.003
Oklahoma	2.304.200	1.171.295	1.594.042	1.574.749		35.2	515.219	514.439		9.7	181.674	115.037	4.3	33.337	1.056.258
Oregon	1.526.724	774.454	1.361.445	1.343.930		25.7	127.593	127.593		2.1	30.841	170.887	3.0	24.360	603.567
Pennsylvania	4.854.988	2.397.703	3.009.010	2.913.789	19.191	50.3	1.871.120	1.708.433	148.793	13.1	193.049	687.680	14.4	39.717	1.542.039
Rhode Island	579.625	255.000	388.193	387.294		6.4	148.206	148.206		1.0				44.125	255.000
South Carolina	1.364.791	692.738	658.144	657.739		20.7	534.349	530.205	4.144	21.8	68.277		1.3	108.571	688.594
South Dakota	1.502.870	761.911	1.132.468	1.132.467		36.9	26.589	26.589		3.5	70.474	29.715	5.1	273.340	732.196
Tennessee	2.123.155	1.121.790	1.498.066	1.492.270		22.5	528.156	491.517	36.639	4.7	118.335	112.621	2.3	21.034	972.529
Texas	6.642.863	3.072.813	3.559.032	3.455.831		96.4	3.010.673	2.784.120		21.1	126.752	44.845	5.6	276.161	3.027.968
Utah	771.826	533.173	692.893	643.814	20.000	17.2	133.237	8.700	116.900	4.9		231.000	6.3	119.312	165.273
Vermont	500.509	240.611	467.259	441.585		12.9	58.924	58.924		1.7		55.000	1.2		185.611
Virginia	2.008.458	941.347	1.255.850	1.228.247		24.1	768.298	476.750	91.957	2.8		150.192	3.6	303.461	699.199
Washington	1.977.260	776.603	1.950.761	1.933.450		32.4	125.116		125.116	3.5		267.958	6.6	43.810	383.529
West Virginia	1.342.270	570.085	631.176	631.176		11.1	718.804	669.205	25.253	10.3	10.795		.1	31.094	544.832
Wisconsin	2,684.067	1.293.455	2.537.584	2.479.515	15.000	52.3	168.329	116.630	51.699	2.7		168.456	4.1	87.922	1.058.299
Wyoming	1,125.332	22.877	1,029.287	1,028.703		22.3	103.839	96.629	6.629	2.6					16.248
District of Columbia	968.235	243.460	725.952	704.305	21.647	4.7	457.597	250.164	207.433	2.0				13.765	14.381
Hawaii															
TOTALS	116.129.696	50.815.336	74.790.151	72.035.634	266.161	1,496.4	41,178.832	35.508.294	3.360.541	444.6	3.404.203	8.302.940	179.6	5.181.565	38,885.694

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF NOVEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 286,761	$ 286,761		15.9	$ 1,587,551	$ 1,587,551		119.7	$ 123,547	$ 329,881	32.0	$ 34,594	$ 735,080
Arizona	525,423	998,032	530,237	517,610		42.3	155,442		$ 139,878	14.5				7,813	858,154
Arkansas	1,484,634	857,024	660,891	659,906		111.3	606,496	601,497		46.3	121,457		3.4	101,773	857,024
California	3,430,440	1,959,203	2,742,860	2,285,839		124.4	1,208,714	1,023,893		54.2	170,709	310,056	13.9		1,689,147
Colorado	1,718,632	871,502	1,625,390	1,579,665		152.8	882,977	110,000	313,313	176.6		103,011	4.1	28,967	455,178
Connecticut	659,120	420,868					885,812	659,120	220,896	19.0					199,972
Delaware	448,864	230,849	202,680	202,680		9.1	276,342	81,450	194,892	48.0	164,733		2.5		35,957
Florida	1,302,816	665,335	1,261,443	1,258,850		74.8	214,156	19,244	194,912	6.3		130,626	5.1	24,722	339,798
Georgia	2,320,973	1,278,373	939,916	938,662		80.9	726,238	726,238		52.0	320,644		18.8	335,428	1,278,373
Idaho	1,121,562	824,450	1,085,506	1,003,679		129.4	549,094	117,819	396,544	63.4		140,363	13.0	64	287,543
Illinois	5,410,040	3,345,525	1,617,971	1,614,813		112.5	4,131,873	3,653,043	478,830	237.9	126,849	1,332,064	71.6	15,335	1,534,631
Indiana	602,271	209,900	251,310	251,310		23.2	347,461	347,461		53.6	3,500	102,591	9.9		107,309
Iowa	2,413,358	1,590,000	1,822,220	1,732,496	15,800	246.5	1,200,039	598,250	444,250	198.6	38,200	559,450	151.9	44,412	570,500
Kansas	2,522,401	1,279,419	1,771,695	1,763,703	5,563	147.0	1,060,414	753,181	307,233	105.8		520,275	31.0	5,517	446,347
Kentucky	1,837,926	1,336,409	1,762,463	1,730,098		205.9	512,927	85,833	410,374	49.2		285,853	39.6	21,995	640,182
Louisiana	1,398,862	838,953	596,741	596,462		30.3	677,249	677,249		29.1		14,741	.8	125,152	824,212
Maine	842,479	427,897	965,702	828,744	60,730	83.4	343,050	5,000	330,153	29.5		16,994	.7	8,735	20,020
Maryland	891,132	1,067,934	613,642	613,642		47.5	469,717	252,997	202,793	25.9	20,419	76,222	6.9	4,073	788,919
Massachusetts	488,185	870,000	469,741	469,741		15.2								18,444	870,000
Michigan	3,184,057	1,613,142	2,322,280	2,322,280		165.7	1,133,550	861,777	238,200	64.0		384,200	14.3		990,742
Minnesota	2,376,415	1,361,813	2,148,243	2,120,326	27,917	205.8	709,191	242,241	303,051	108.5		239,952	27.1	13,848	790,894
Mississippi	1,744,669	354,022	54,182	54,182		9.2	1,394,146	1,394,146		138.8	132,896		11.4	163,445	354,023
Missouri	2,923,273	1,852,122	2,722,227	2,615,655	44,922	515.6	659,932	212,571	447,361	191.2	4,361	616,646	133.9	90,686	743,192
Montana	1,859,937	942,434	1,845,330	1,834,423		226.1	48,525		48,525			283,705	27.9	25,514	610,203
Nebraska	1,957,240	991,091	1,296,979	1,287,084	7,824	209.2	1,090,225	645,990	443,985	176.1		199,257	63.2	24,166	340,025
Nevada	1,136,479	852,000	1,124,565	1,028,658	75,273	133.3	253,557	72,661	130,528	22.3		89,858	16.2	35,160	556,342
New Hampshire	477,460	242,365	412,780	371,791		22.1	169,678	105,172	63,942	7.5		68,066	3.3	497	110,357
New Jersey	56,550	460,000	56,528	55,098		.5								1,452	460,000
New Mexico	1,272,129	735,425	1,185,770	1,185,770		206.6	154,040	75,664	78,376	26.1		39,214	5.6	10,695	617,834
New York	3,608,768	4,252,400	3,085,376	2,919,351	4,200	81.1	3,334,300	676,975	1,690,600	112.7		1,413,740	114.0	12,442	1,143,860
North Carolina	2,380,573	1,590,637	1,832,167	1,831,389		193.5	632,359	475,544	156,815	57.9		445,677	53.7	73,639	988,145
North Dakota	1,451,112	734,742	819,429	819,429		261.6	321,441	321,441		91.8	114,141	20,647	52.0	196,102	714,095
Ohio	3,871,148	1,966,253	3,799,695	3,545,417		291.2	622,270	323,903	240,500	60.1		263,400	40.7	1,828	1,462,353
Oklahoma	2,304,199	1,171,295	998,064	980,096		147.4	1,362,330	1,295,833		128.2	5,479	273,084	9.7	22,792	898,211
Oregon	1,526,724	774,454	1,469,447	1,270,753	13,322	104.7	651,721	246,968	380,788	33.7		84,987	12.2	9,003	295,358
Pennsylvania	7,344,822	2,639,003	5,487,926	5,356,085		464.3	3,124,285	1,983,112	1,133,199	270.2	5,625	852,620	27.8		653,184
Rhode Island	439,716	295,000	350,421	348,280		28.6	60,357	60,357		4.5				31,080	295,000
South Carolina	1,364,791	692,739	820,981	820,981		87.5	521,500	472,524	48,976	64.1		398,542	37.4	71,286	245,221
South Dakota	1,502,870	761,911	1,064,542	1,064,529		309.5	431,493	387,964	43,529	117.7	34,544		28.3	15,833	718,381
Tennessee	2,123,155	1,075,748	1,217,153	1,195,620		102.4	948,186	861,645	86,541	52.8		312,381	17.2	65,890	676,826
Texas	6,012,518	3,072,813	5,482,785	5,091,029		714.4	902,898	874,074		52.3		672,608	38.0	47,416	2,400,205
Utah	1,048,677	533,173	1,025,455	903,620	37,500	161.2	335,149	132,945	160,300	59.6		35,000	5.3	12,112	300,373
Vermont	438,880	241,354	376,609	363,822		29.4	192,477	75,058	104,976	14.3		72,291	5.5		64,088
Virginia	1,699,920	941,347	1,403,970	1,362,039		199.4	349,903	278,139	43,015	18.0	11,450	60,496	2.9	48,291	837,835
Washington	1,080,673	776,603	932,259	915,000		60.4	277,170	163,455	113,715	11.8		446,158	35.0	2,218	216,730
West Virginia	1,118,559	570,083	536,043	528,965		28.2	532,022	506,887		28.9	48,468		.1	34,238	570,083
Wisconsin	2,425,385	1,782,435	2,340,560	2,169,244	40,000	170.4	408,513	155,767	142,852	9.6	82,822	246,829	11.8	17,553	1,352,754
Wyoming	1,125,332	571,928	1,081,608	1,064,346		148.4	90,037		90,035	12.3		193,656	28.7	60,985	288,237
District of Columbia	950,234	730,382	931,582	931,582		7.7	238,535		238,535	2.6		312,510	1.8	18,652	179,336
Hawaii	187,106	351,000					177,718	177,718		4.9				9,383	351,000
TOTALS	92,494,941	55,106,347	67,432,125	64,691,505	333,051	6,937.8	36,963,060	24,380,357	10,062,412	3,272.1	1,529,844	11,947,651	1,230.2	1,893,235	32,763,233

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF NOVEMBER 30, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370.133	$ 4,259,842	$ 5,455,019	$ 3,466,100	$ 35,889	273.4	$ 5,612,237	$ 4,333,331	$ 158.342	333.3	$ 229,219	$ 819,637	65.7	$ 341,434	$ 3,245,973
Arizona	5,211.960	2,641,935	5,359,695	4,749.966	6.592	339.2	1,047.595	202,559	819,181	67.5	133,977	75,613	3.3	125.458	1,740,548
Arkansas	6,748,335	3,428,049	3,770,175	3,282,616		239.3	3,159,581	2.956,357		135.7	309,275	596,802	28.7	200,087	2,831.247
California	15,607,354	7,932,206	13.724.540	11,002,306		411.9	7,311,167	4,405,023	876,645	147.5	170,708	723,356	27.9	29,317	6,332,205
Colorado	6,874,530	3,486,006	6,584,695	6,473,009		329.4	2,777,524	323.642	1,870,511	271.3		457,019	13.1	77,879	1.158,476
Connecticut	2,865,740	1.454,868	1.372,214	1,368,130		20.9	2,399,980	1.497,025	725,811	44.6	584	168,419	1.2		560,637
Delaware	1,819,088	923,395	1,434,781	1.424,406		33.5	916,536	199,755	701,603	60.3	169,652		2.5	25.274	221,792
Florida	5,231,834	2.661.343	4,988,689	4,018,540		188.5	1,540,310	1,083,313	342,386	31.3	66.146	461.641	18.1	63.834	1,857.317
Georgia	10,091.185	5,113.491	4,887.364	4,862.257		328.5	3,123,914	2,979,769		163.9	1.066,321	139.839	45.8	1,182,838	4,973,652
Idaho	4,486,249	2,277.486	3,992,077	3.790,126	16,886	326.5	1,496,380	635,673	793,456	88.7		210,460	23.8	60.445	1,256,684
Illinois	17.570.770	8,921,401	8.036,735	7.984,158		195.3	9.666,968	8.980,211	673.775	287.6	463,733	1,778,140	80.5	142,668	6,469,486
Indiana	10,037.843	5.088,963	3.938,563	3,927,499		134.8	4.828,786	4,828,099		146.3	886,609	225,847	31.2	395,636	4,863,116
Iowa	10.055,560	5,118.361	8,135.781	7.772.161	18,430	536.0	4,112,484	2,026,758	1,721,540	355.9	184,200	1,252,435	189.6	72,541	2,125,906
Kansas	10,089,604	5,117.675	8.720,227	8.541,485	42,436	591.6	3.274,213	1,418,036	1,555,647	298.2	32,129	1.379.459	128.6	97,955	2,140,134
Kentucky	7,517.359	3,818.311	6,033.256	5,826.108		456.8	2,212,191	1,349.934	723.461	109.0	157.933	701,008	76.0	183,383	2,393,842
Louisiana	5,828.591	2,963.932	2,690,811	2,689,298		104.5	3,460.494	2,680.542	246.707	67.4	130,409	230,436	3.5	328,342	2,436,789
Maine	3,369,917	1,711,586	3.072,769	2.907,613	60,730	142.9	1,158,170	235,225	854,577	42.6		311,870	8.6	177.079	434,408
Maryland	3.564,527	1,810,058	1,437.851	1.424,052		61.1	2,505.175	1.368,349	309,380	47.6	225,183	89.882	11.2	546.943	1,410,797
Massachusetts	6.597.100	3.350,474	2,667,233	2,336,437		54.3	4,175,452	4,046,776		15.2		943,752	11.5	213,887	2.406,722
Michigan	12,736.227	6,452,568	8,173,874	8,149,657		373.4	5,941,798	4,556,650	1,290,075	197.1	6,461	1,282,375	36.9	23,459	3,880,118
Minnesota	10,656,569	5.425.551	10,570,794	9,218.751	1.260,278	1.112.2	2,245,733	851.066	1.149,567	269.7		717,106	95.2	586,753	2,298,600
Mississippi	6.978,675	3.540.227	3.093,940	1,914,667		166.0	5.571.779	3.765.717	363,931	339.1	548,157	430.695	57.7	750,134	2,745,602
Missouri	12.180,306	6.173,740	9.272.732	8,489,067	44,923	743.9	4,577,055	2,752.323	1.594,782	271.2	417,164	1.379.442	150.4	521,753	3,154,593
Montana	7.439,748	3,769,734	8,014,341	7,317,179	109,308	642.6	1,560,920	49,846	1,354,082	175.9	8,796	918,590	70.2	63,927	1.387,754
Nebraska	7.828,961	3,964,364	6,697,585	5,578,744	27,616	542.5	4.162.578	2,170,061	1,537,485	301.3		606.284	85.4	80,155	1.792,978
Nevada	4,545,917	2,302,356	4,346,210	4,180,044	75,273	401.2	825,272	205,725	569,179	70.6		438.228	78.3	160,149	1,219,676
New Hampshire	1.909,839	969.462	1,751,985	1,693,139		48.5	660,351	184,191	460,430	18.3		301,755	8.2	32,509	207,276
New Jersey	6.346,039	3,220.879	3,312.007	3,216,685		42.9	3.119.995	2,926,396		27.5	97,912	506,030	6.9	105,046	2,714,850
New Mexico	5.792,935	2,941,700	5,396,265	5,252,336		510.5	1.682,275	330,905	1.301,370	139.1		198,269	14.6	159,694	1.442,061
New York	22,330,101	11,327,921	15,937.369	14,695,140	15,200	302.3	16,854,124	7,610,034	4,340,700	294.1		3,601,796	145.3	24,926	3,370,225
North Carolina	9,522,293	4.840,941	7.586,721	6.943,951	19.918	792.4	2,473,725	1,537,702	476,082	217.8	457,081	495,375	74.3	583,558	3.849,566
North Dakota	5,804,448	2,938,967	4,778,178	4,386,979	16,672	1,261.0	933.130	685.701	138,626	209.5	421,962	552,601	281.2	309,806	2,231,068
Ohio	15,484.592	7.865,012	15.483,422	14,420,449		535.6	1,703.480	876.989	628.320	77.4		2.870,180	91.6	187,153	4.366,512
Oklahoma	9,216,798	4,685,180	6.025,725	5,933,373		450.7	2,817,448	2,743,936		173.6	368,153	1,391,617	74.3	171,336	3,293,563
Oregon	6,106,896	3.097,814	6.085,614	5.575.817	13,322	312.6	1,935,391	434,058	1.362,623	83.9	30,841	319,971	15.6	66,180	1,401,399
Pennsylvania	18,891.004	9,590,788	12,784,401	12.445,939	36,580	622.4	9.301,346	6,113,729	2.906.767	343.2	209,540	2,673,877	69.7	121.796	3,973,564
Rhode Island	1.998.708	1.014.572	1,734,643	1,668,736		55.6	424,280	208.562	215,718	12.2	46,205	245,737	4.8	75,205	553,117
South Carolina	5,459,165	2.770,954	2.598,912	2,595.632		211.2	2,753,725	2,574,547	162,744	229.0	82,777	710,818	61.0	206,210	1.897.392
South Dakota	6,011,479	3,047,643	4,637,945	4,334,061		754.3	1.415,424	1,210,928	43,529	254.8	177,318	558,436	197.5	289,173	2.445,678
Tennessee	8,492.619	4,302,991	6,313,864	5,685.513		265.2	2,700,328	2,323.087	377,241	108.9	334,370	1,033,060	45.7	149.649	2,892,690
Texas	24,244,024	12,291,253	19,088,615	18,087.015		1.704.7	6,054.266	5.581.709	156,017	207.7	126,752	3,082,778	225.4	448,549	9,052,458
Utah	4,194,708	2,132,691	4.066.790	3,708.218	186,500	382.4	1,419,415	315,217	815,800	147.8		289,242	14.3	171,273	841.149
Vermont	1.867.573	948,007	1.693.757	1.612,697	10,073	85.0	637,898	250,728	356.949	33.4		152,938	8.2	4,148	428,047
Virginia	7,416,757	3.765,387	5,905.216	5,723.782		366.6	1,589.870	1.046,462	203,179	35.3	37.930	1.304,171	51.3	608,582	2,258,037
Washington	6,115,867	3.106,412	5,465,044	5,421.605		187.6	1,402,324	600,384	801,940	39.5	1,485	943,088	48.8	92,394	1,361,384
West Virginia	4,474,234	2,280.335	2,843,066	2,826,873		100.5	2,068,438	1.502,458	499,608	69.0	59.263	208,412	7.5	85,640	1,572,315
Wisconsin	9.724,881	4,941,837	9,326,841	8.931.593	55,500	435.8	1,194,281	517,827	522,249	48.2	82,822	585,243	23.8	142,640	3,778,845
Wyoming	4,501,327	2,287.712	4,431.772	4,118,516	67.583	639.0	1,153.256	290,605	835,327	133.3		367,899	74.3	92,205	1,016,903
District of Columbia	1.918.469	973.842	1,657.535	1.635,888	21,647	12.4	696,132	250,164	445,968	4.6		312,510	1.8	32,417	193,717
Hawaii	1,871.062	949.778	254,428	178,070		10.9	1.943,876	1.615,564		32.9	66.000		.7	11.428	949.778
TOTALS	394.000.000	200,000,000	295,632.066	273.836,383	2,141,406	18.840.3	156.599.070	101.733.653	37.283,310	7,279.8	7,807,067	39,044,138	2.891.7	10,622.897	121,531,146

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PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 11 JANUARY 1935

ROAD-MIX CONSTRUCTION IN CALIFORNIA

For sale by the Superintendent of Documents, Washington, D. C. - See page 2 of cover for prices

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BUREAU OF PUBLIC ROADS

Volume 15, No. 11 January 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is reqired for the proper transaction of the public business

EXPERIMENTS WITH ROAD-MIXES AND SURFACE TREATMENTS IN CALIFORNIA

Reported by T. E. STANTON, Materials and Research Engineer, Division of Highways, California, and J. T. PAULS, Senior Highway Engineer ,U. S. Bureau of Public Roads

LIQUID asphaltic materials of the slow-curing type have been used extensively in the Western States during the last few years in the construction of the road-mix or mixed-in-place types of surfaces. In general, they have given satisfactory results in the arid and semiarid sections. However, these materials have not been entirely satisfactory in the more humid areas or with certain kinds of aggregates, and a need has been felt for some experimental work to determine the limitations of the materials and to obtain information as to other materials and methods of construction which might be used to better advantage under these special conditions.

The series of experimental sections described in this report included a wide range in the features commonly involved in the construction of the road-mix and surface-treatment types.

The experimental sections were built during 1929 and 1930 by the division of highways, California Department of Public Works, in cooperation with the Bureau of Public Roads. The 21 sections cover a length of 10 miles on U. S. 30, beginning at the California-Nevada State line and extending southwest toward Truckee.

EXPERIMENTS COVERED A NUMBER OF TYPES OF CONSTRUCTION

The experiments are grouped with respect to the type of construction and materials used as follows:

1. Road-mixes of crushed stone and gravel aggregates with different types and grades of bituminous materials.
2. Surface treatment of road-mixes.
3. Surface treatments on a traffic-bound stone base course.

The location of the different experiments and the details of their construction are given in tables 1 and 7.

The road on which the experimental sections were built had been graded and drained and surfaced with selected soil containing some granular material. In the summer of 1927, following this construction, an oil-mixed surface from 2 to 3 inches in thickness was built using local aggregate. On the westerly 3 miles a crushed red volcanic ash was used in the surface mix and this surfacing failed extensively. The remaining 7 miles, on which crushed granite had been used, was in better, condition but, in general, failure had developed on the whole project to such an extent that reconstruction of the surface was necessary at the time the experiments were begun. Figure 1 is an illustration of a condition typical of the old surface.

The road is in a section where the climate is severe and the moisture conditions are unfavorable. The average elevation is more than 5,000 feet and the range in temperature is from about 95° F. above zero to as low as −30° F. Considerable snow lies on the road until late in the spring and, as the road is located largely in heavy sidehill cuts, the moisture conditions during winter and spring are particularly bad, due to the heavy flow of water and sliding of earth which occur at this time of year. Figure 2 shows a typical condition during the spring. Yearly traffic counts over the period from 1929 to 1933 show a daily traffic on week days of 1,300 vehicles and as many as 3,500 vehicles are counted on Sundays.

Subgrade samples were taken at intervals under the edge of the old surface and the results of analyses are given in table 2.

The experimental sections were each approximately one-half mile in length, with the exception of sections 11, 12, and 13, which were one-third mile. Sections were numbered from east to west beginning at the State line and ending with section 21 at the west end of the project. The surface was made 20 feet wide in all cases and the compacted thickness of both the road-mix surfacing and also the traffic-bound stone course for surface treatment was 3 inches.

As a basis for correlation of data obtained on materials, methods of construction, and service behavior, two observation or test points were selected in each section, approximately 700 feet from each end. The locations of these points were marked in the field by 3- by 3-inch painted posts and identified by the number of the section and the letter A if near the easterly end, and B if near the westerly end. At these points samples were taken to determine the condition of the old surface and the character of the subgrade soil. Immediately prior to applying the bituminous material the aggregate was sampled to determine the moisture content and the mechanical analysis. Samples of the surface mixture were taken at these locations during compaction and at several intervals thereafter. Results of tests on these samples to determine the bitumen content, grading, and stability are given in table 3. Wherever the right or left portion of the roadway is mentioned in the report the reference is to the right and left of an observer facing in the direction of the stationing and the beginning of the project.

Except for the ¾- to ⅛-inch stone, the crushed stone used was produced locally at a roadside crushing plant shown in figure 3. The local material was a highly weathered granite, friable and very light, the crusher-run material weighing only about 2,300 pounds per cubic yard, and the open-graded material weighed 1,970 pounds. The ¾- to ⅛-inch stone was the same type of material but of somewhat better quality and was shipped in by rail from Oroville, Calif. The fine material, known locally as muck sand, which was added to the aggregate on several of the sections to increase the percentage passing the no. 200 sieve, was shipped in by rail from Sacramento. Washed gravel, 1 to ⅜ inch in size, and crushed gravel ranging from ⁹⁄₁₆-inch to dust, were obtained from Fair Oaks, Calif. Combinations of these sizes were used on the road-mix sections and satisfactory mixing was obtained by depositing the materials on the subgrade in the proportions of 25 percent of the coarser uncrushed gravel to 75 percent of the finer crushed gravel and blading it in windrows.

Table 1.—*Materials used on road-mix experimental sections. All sections were surfaced with 3 inches of compacted material placed in 1929 and seal treatments were given to some sections in 1929 and 1930*

SECTION	13	12	11	10	9	8	7	6	5	4	3	2	1
TYPE OF BITUMINOUS MATERIAL AND QUANTITY APPLIED IN GALLONS PER SQUARE YARD	95+L ASPHALTIC EMULSION 2.00 GALS AGGREGATE PREMIXED WITH WATER AT RATE OF 2.23 GALS PER SQ YD	95+M ASPHALTIC EMULSION, 1.84 GALS PREMIXED WITH 60-70 SLOW-CURING OIL, .70 GAL ENRICHED WITH 110-120 M ASPHALTIC EMULSION, .23 GAL	110-120 M ASPHALTIC EMULSION, 1.54 GALS PREMIXED WITH 60-70 SLOW-CURING OIL .48 GAL ENRICHED WITH 95+M ASPHALTIC EMULSION, .49 GAL	94+ ASPHALTIC OIL CUT BACK WITH KEROSENE, 1.58 GALS, AND 110-120 CUT-BACK ASPHALT, .14 GAL	94+ ASPHALTIC OIL CUT BACK WITH KEROSENE, 1.86 GALS	70-80 SLOW-CURING OIL, 1.24 GALS	70-80 SLOW-CURING OIL, 2.16 GALS	60-70 SLOW-CURING OIL, 1.40 GALS.	60-70 SLOW-CURING OIL, 1.70 GALS	60-70 SLOW-CURING OIL, 1.78 GALS	60-70 SLOW-CURING OIL, 1.70 GALS.	110-120 ASPHALT CUT BACK WITH KEROSENE, 1.40 GALS	110-120 ASPHALT CUT BACK WITH KEROSENE, APPLIED AS FOLLOWS 2.47 GALS-1320' 1.98 GALS 660' 1.71 GALS 639'
TYPE AND SIZE OF AGGREGATE	CRUSHED STONE, ¾ INCH TO DUST	CRUSHED STONE, ¾ INCH TO DUST	CRUSHED STONE, ¾ INCH TO DUST	CRUSHED GRAVEL, 75 PERCENT 9/16 INCH TO DUST, 25 PERCENT 1 INCH TO ⅛ INCH	CRUSHED STONE, ¾ INCH TO DUST WITH 12.7 PERCENT FINES ADDED	CRUSHED STONE, ¾ INCH TO ¼ INCH	CRUSHED STONE, ¾ INCH TO DUST WITH 8.8 PERCENT FINES ADDED	CRUSHED STONE, ¾ INCH TO DUST	CRUSHED STONE, ¾ INCH TO DUST WITH 5.7 PERCENT FINES ADDED	CRUSHED STONE, ¾ INCH TO DUST WITH 6.4 PERCENT FINES ADDED	CRUSHED GRAVEL, 75 PERCENT 9/16 INCH TO DUST, 25 PERCENT 1 INCH TO ⅛ INCH	CRUSHED STONE, ¾ INCH TO ⅛ INCH	CRUSHED STONE, ¾ INCH TO DUST 6.5 PERCENT FINES ADDED
BITUMINOUS MATERIAL AND COVER USED IN SEAL TREATMENT	95+L2 ASPHALTIC EMULSION WITH ¼ INCH TO ⅛ INCH CRUSHED STONE COVER RIGHT - [illegible] GAL EMULSION, 11 POUNDS COVER LEFT - .18 GAL EMULSION, 13 POUNDS COVER 95+L ASPHALTIC EMULSION, .3 GAL. COVER MATERIAL, CRUSHED STONE, ¼ INCH TO ⅛ INCH, 11 POUNDS	95+L2 ASPHALTIC EMULSION, .21 GAL ON RIGHT AND .18 GAL ON LEFT; COVER MATERIAL, CRUSHED STONE, ¼ INCH TO ⅛ INCH. [illegible] POUNDS. MIXTURE OF 95+M AND 95+L ASPHALTIC EMULSION, .3 GAL. COVER MATERIAL CRUSHED STONE, ¼ INCH TO ⅛ INCH, 11 POUNDS	95+L2 ASPHALTIC EMULSION, .17 GAL ON RIGHT AND .16 GAL ON LEFT. COVER MATERIAL, CRUSHED STONE, ¼ INCH TO ⅛ INCH, 11 POUNDS MIXTURE OF 95+M AND 95+L ASPHALTIC EMULSION, .3 GAL. COVER MATERIAL, CRUSHED STONE, ⅝ INCH TO ⅛ INCH, 11 POUNDS					94+ ASPHALTIC OIL, APPLIED HOT, .28 GAL ON RIGHT AND .22 GAL ON LEFT. COVER MATERIAL, CRUSHED STONE, ¼ INCH TO ⅛ INCH, 18.7 POUNDS.	60-70 SLOW-CURING OIL, .17 GAL. ON RIGHT AND .10 GAL ON LEFT. COVER MATERIAL, CRUSHED STONE, ¼ INCH TO ⅛ INCH, 19 POUNDS	540+44 = 0+00			STATE LINE
	306+23 311+23 326+13	331+09 340+89 345+79	349+69 35[illegible]+49 361+34	387+82	[illegible]	[illegible]+67	467+07	493+47	510+55	6+70	33+10	59+50	85+69

Table 2.—*Results of tests on subgrade soil samples*

Section and location	Mechanical analysis [1]						Physical characteristics of material passing no. 40 sieve						Soil group
	Particles larger than 2 millimeters	Particles smaller than 2 millimeters					Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Moisture equivalent		
		Coarse sand, 2 to 0.25 millimeters	Fine sand, 0.25 to 0.05 millimeter	Silt, 0.05 to 0.005 millimeter	Clay, less than 0.005 millimeter	Colloids, less than 0.001 millimeter					Centrifuge	Field	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*							
1, A	41	52	30	14	4	2	22	5	18	1.8	15	18	A-2, plastic.
B	27	42	32	19	7	1	36	16	19	1.8	34	25	A-4.
2, A	42	60	23	14	3	2	20	------	------	------	14	19	A-2, nonplastic.
B	42	60	28	10	2	------	23	5	20	1.7	17	20	A-2, plastic.
3, A	39	53	29	15	3	2	23	3	------	------	17	21	Do.
B	51	41	30	23	6	2	31	11	21	1.7	28	25	A-4.
4, A	39	62	22	13	3	2	26	6	19	1.7	19	22	A-2, plastic.
B	46	41	33	20	6	2	39	17	19	1.7	33	30	A-7.
5, A	28	37	27	14	13	6	38	16	18	1.8	35	29	Do.
B	50	54	26	14	6	2	31	10	21	1.7	23	26	A-2, plastic.
6, A	14	51	26	18	5	1	24	4	------	------	16	22	Do.
B	51	45	31	14	10	4	29	5	21	1.7	23	26	Do.
7, A	26	34	35	24	7	1	29	9	21	1.7	25	25	Do.
B	39	28	38	21	13	5	32	11	22	1.7	24	26	Do.
8, A	40	35	35	22	8	2	27	6	22	1.7	22	24	A-4.
B	41	22	41	25	12	5	36	14	21	1.7	32	30	Do.
9, A	30	38	28	27	7	1	39	19	20	1.7	33	30	A-7.
B	24	47	35	15	3	1	26	6	22	1.7	15	23	A-2, plastic.
10, A	30	51	30	16	3	1	23	4	22	1.7	19	21	Do.
B	29	20	17	33	30	13	52	23	26	1.6	49	43	A-7.
11, A	24	38	29	23	10	3	35	15	19	1.7	32	27	A-4.
12	45	27	24	34	15	5	46	19	23	1.6	48	39	A-7.
13	38	23	24	42	11	2	37	12	20	1.7	41	29	A-4.
15, B	43	35	33	20	12	5	19	------	------	------	17	22	A-2, nonplastic.
16, B	39	38	42	13	7	3	22	------	------	------	15	22	Do.
17, B	26	28	36	23	13	5	23	3	22	1.6	26	24	A-4.
18, A	27	27	31	24	18	8	27	8	24	1.6	30	27	A-4.
B	37	49	35	11	5	3	27	------	------	------	23	29	A-2, nonplastic.
19, A	28	25	31	23	21	8	31	7	27	1.6	39	31	Do.
20, A	4	17	25	28	30	16	51	27	17	1.8	56	39	A-7.
B	37	24	32	23	21	13	27	7	21	1.7	27	22	A-4.
21, A	46	11	24	39	26	11	48	17	34	1.4	58	41	A-5.
B	2	4	18	49	29	8	69	27	33	1.4	78	58	Do.

[1] Particles above 0.074 mm in diameter by sieve method; particles below 0.074 mm in diameter by the hydrometer method.

GENERAL METHOD OF CONSTRUCTING ROAD-MIX SECTIONS DESCRIBED

The road-mix type of construction was used on sections, 1 to 13, inclusive. The bituminous materials used on these sections included slow-curing oils of 60–70 and 70–80 asphalt content, medium-curing kerosene cut backs of 94+ asphaltic oil and of 110–120 penetration asphalt, and emulsions of 95+ asphaltic oil and 110–120 penetration asphalt designated as 95+ M, 95+ L and 110–120 M, respectively. Analyses of the bituminous materials are given in tables 4 and 5. Tests on these materials were made according to the methods used at the time of construction and are therefore not those now generally advocated. The approximate Saybolt-Furol viscosity values have, however, been included in the tables to facilitate comparison with present grades of asphaltic materials.

With the exception of the 70–80 slow-curing oil, the consistencies of the liquid asphaltic materials used in the road-mix sections, expressed as specific viscosity, Engler, at 122° F., ranged from 64 to 100. In terms of Saybolt-Furol viscosity, the range is from 255 to 400 seconds. For the medium-curing cut-back materials, 20 to 25 percent of kerosene was required in the manufacture to soften the base asphalt to the required consistency.

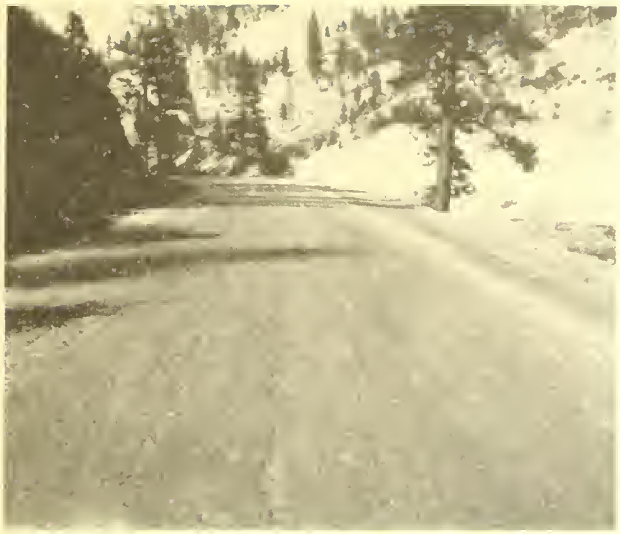

Figure 1.—Typical Condition of the Old Surface at Time of Construction.

The bituminous materials were delivered in tank cars which were heated to about 100° to 150° F.; the asphalt was pumped into tank trucks and hauled to the job. A detachable pressure distributor was used for spreading.

The aggregate was hauled in trucks and dumped in two windrows, one on each edge of the roadbed. The correct amount of aggregate was obtained by measuring the loads at the place of loading and spreading them over measured distances on the road. On those sections requiring the addition of fines, the procedure was to add this material to the top of the windrows and then mix the two together before applying the oil. The grading of the aggregate was determined by frequent sampling and testing at the loading plant and by later tests on the material in the windrows immediately before applying the oil. The amount of fines or filler to be added was determined from frequent mechanical analyses of the aggregate at the loading plant.

A typical grading of the fine muck-sand added to the crusher-run aggregate on a number of the sections to increase the percentage of material passing the no. 200 sieve was as follows:

Screen or sieve size:	*Percent passing*
¼ inch	100. 0
No. 10	99. 7
No. 20	99. 0
No. 30	98. 7
No. 40	98. 0
No. 50	97. 2
No. 80	89. 4
No. 100	82. 0
No. 200	57. 3

The amount of bituminous material required was determined largely from the appearance of the mix, the grading of the aggregate, and the results obtained during the progress of the work. The detailed descriptions of the sections show the grading of the aggregate and the amount of water determined at the time of mixing. Table 3 gives additional information from tests made on the mixes at different intervals following the construction. Comparisons, of the amount of oil used and that required according to various formulas based on the grading of the aggregate can be made from the data in table 6.

Prior to adding the bituminous material, one windrow of aggregate was moved to about midway between the edge and the center of the roadway and spread to a width of approximately 10 feet. The oil was then applied in three applications and disked in after each application. After the last application of oil, the materials were mixed with blade machines, using the usual turn-over method, until the aggregate had a uniform coating. It was then left in a windrow at the edge of the road and the same procedure was followed on the opposite windrow, after which the 2 were combined and mixed again 5 or 6 times to insure uniformity.

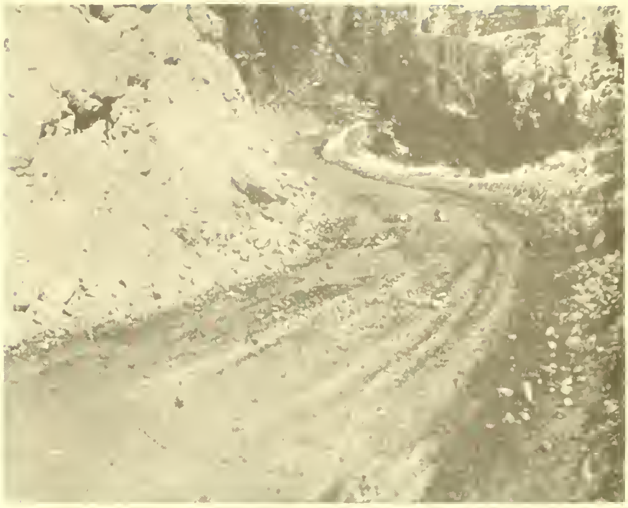

Figure 2.—During the Spring, Slides Caused Poor Drainage at Numerous Points.

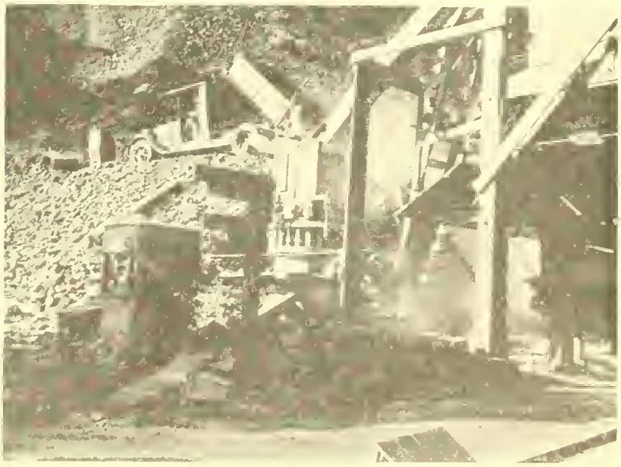

Figure 3.—The Roadside Crushing Plant Consisting of a Jaw Crusher and a Gyratory Crusher.

In the construction of those sections where emulsions were used it was found advantageous to blade the material into a windrow following each application of oil and subsequent disking. Blade machines were used, one on each edge of the material, each turning toward the other, followed by a third machine which flattened the windrow thus formed in preparation for the next application. The arrangement of equipment is shown on the cover page.

Upon the completion of the mixing process the material was windrowed to the center of the road and spread by blading toward each edge. After spreading to the full width, a light power grader was used to smooth and maintain the surface.

TABLE 3.—*Results of tests of samples from mixed surfaces*

Section and location	Date sampled	Data on mix			Analyses of samples by weight						Results of tests on oiled material passing no. 10 sieve						
		Bituminous material		Aggregate	Grading of mineral aggregate after extraction. Dry aggregate passing—				Extracted bitumen	Water	Loss of volatile matter from binder in Hubbard-Field specimens cured at 60° C.[1]			Hubbard-Field stability at 25° C.			
		Type	Gallons per square yard		1-inch screen	¼-inch screen	No. 10 seive	No. 200 seive			1 day	5 days	10 days	As made	Cured at 60° C.		
															1 day	5 days	10 days
					Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1, A	Sept. 17, 1929 [2]	110-120 asphalt cut back with kerosene.	1.71	Crushed stone, ¾ inch to dust	100.0	36.7	24.7	4.4	4.0	0.2	[3] 10.16	[3] 17.22	[3] 18.89	---	---	---	---
A	June 25, 1930				100.0	45.3	26.6	4.9	3.3	.7							
B	Sept. 17, 1929 [2]	do	1.92	Crushed stone, ¾ inch to dust with fines added.	100.0	41.5	28.8	6.3	3.9	.3	[3] 10.93	[3] 20.59	[3] 21.92	---	---	---	---
B	June 25, 1930				100.0	46.1	29.8	7.0	3.6	.9							
C	Sept. 17, 1929 [2]	do	2.47	do	100.0	45.3	32.9	9.4	4.3	.4	[3] 11.73	[3] 19.57	[3] 20.74	---	---	---	---
C	June 23, 1930				100.0	49.0	33.6	8.8	3.3	2.0							
2, A	Sept. 7, 1929 [2]	do	1.40	Crushed stone, ¾ to ⅛ inch	100.0	35.5	13.9	2.6	3.8	.1	[3] 5.21	[3] 9.01	[3] 11.02	---	---	---	---
A	June 23, 1930				100.0	41.3	14.3	3.0	3.4	.1							
B	Sept. 7, 1929 [2]				100.0	35.6	14.7	3.2	4.0	.1	[3] 4.89	[3] 8.55	[3] 10.26	---	---	---	---
B	June 23, 1930				100.0	39.7	14.8	3.8	3.7	.1							
3, A	Sept. 6, 1929 [2]	60-70 slow-curing oil	1.70	Gravel 1 inch to dust, 25 percent 1 to ⅛ inch uncrushed and 75 percent 9/16 inch to dust crushed.	95.0	44.7	33.8	6.7	2.9	.2	2.27	4.58	5.38	1,925	2,575	2,825	2,935
A	June 23, 1930				87.0	47.4	35.2	7.2	3.8	.2							
B	Sept. 6, 1929 [2]				94.7	51.7	43.7	8.5	4.2	.1	2.27	3.15	3.24	---	2,300	2,625	2,625
B	June 23, 1930				93.2	58.0	44.0	9.1	3.7	.8							
4, A	Sept. 3, 1929 [2]	do	1.78	Crushed stone, ¾ inch to dust with fines added.	100.0	39.1	30.7	7.8	2.8	1.0	4.37	9.76	11.18	2,575	3,625	4,375	4,150
A	Sept. 21, 1930				95.0	49.4	35.1	8.5	3.2	1.5							
B	Sept. 3, 1929 [2]				100.0	46.0	35.3	8.9	3.5	.8	---	9.07	11.85	2,375	3,610	4,300	4,075
B	June 21, 1930				100.0	41.7	29.4	7.7	2.9	.9					[4] 2,875	---	[4] 3,660
5, A	Sept. 3, 1929 [2]	do	1.70	do	100.0	54.9	40.6	10.3	2.7	1.3	5.32	10.33	11.59	2,675	3,575	4,175	4,125
A	May 21, 1930				100.0	53.9	39.4	10.4	[5] 3.2	1.2					[4] 2,975	---	[4] 3,560
B	Sept. 3, 1929 [2]				100.0	47.7	35.3	8.6	3.0	.7	6.75	12.08	12.76	2,800	4,100	5,175	4,075
B	May 21, 1930				100.0	55.6	37.7	9.9	[5] 3.6	.9							
6, A	Aug. 16, 1929 [2]	do	1.40	Crusher-run stone, ¾ inch to dust	100.0	46.7	34.0	6.9	3.5	.0	7.73	---	11.96	2,375	3,610	4,435	4,075
A	May 21, 1930				100.0	51.5	34.6	8.1	[5] 4.0	.8					[4] 3,400	---	[4] 3,450
B	Aug. 16, 1929 [2]				100.0	63.9	45.0	8.8	---	---	4.97	11.00	11.75	---	3,975	4,375	4,085
B	June 21, 1930				100.0	49.8	33.3	8.5	[5] 3.6	1.3							
7, A	Sept. 17, 1929 [2]	70-80 slow-curing oil	2.16	Crushed stone, ¾ inch to dust with fines added.	100.0	54.5	40.7	10.7	4.4	.8	---	---	---	---	---	---	---
A	June 21, 1930				100.0	64.1	45.7	12.3	4.4	.6							
B	Sept. 17, 1929 [2]				97.5	42.0	32.8	8.8	5.3	.4	[3] 7.68	[2] 12.28	[3] 12.62	---	---	---	---
B	June 21, 1930				100.0	55.5	39.1	11.6	5.8	.7							
8, A	Sept. 23, 1929 [2]	do	1.24	Crushed stone, ¾ inch to ⅛ inch	100.0	32.5	17.0	3.9	3.3	.0	[3] 4.48	[2] 5.38	[3] 6.05	---	---	---	---
A	June 20, 1930				100.0	35.9	14.8	4.1	3.6	.2							
B	Sept. 23, 1929 [2]				100.0	36.5	18.3	4.9	3.2	.2	[3] 6.18	[2] 8.83	[3] 9.49	---	---	---	---
B	June 20, 1930				100.0	46.6	18.0	5.0	3.4	.2							
9, A	June 23, 1929 [2]	94+ asphaltic oil cut back with kerosene.	1.86	Crushed stone, ¾ inch to dust with fines added.	100.0	43.5	32.4	9.2	4.1	.7	1.95	---	6.45	---	3,300	---	5,235
A	June 20, 1930				100.0	41.3	28.4	8.5	3.4	1.4							
B	Sept. 23, 1929 [2]				100.0	35.6	28.0	9.3	4.6	.4	1.66	5.12	6.09	---	3,675	4,435	4,135
B	June 20, 1930				100.0	45.7	31.6	10.6	3.5	.9							
10, A	Sept. 24, 1929 [2]	do	1.72	Gravel, 1 inch to dust, 25 percent 1 to ⅛ inch uncrushed, 75 percent 9/16 inch to dust crushed.	100.0	76.5	52.1	11.5	3.8	.0	1.70	5.18	5.89	---	3,575	5,265	6,000
A	May 19, 1930				100.0	66.7	46.0	9.8	4.0	.1							
B	Sept. 4, 1929 [2]				100.0	62.1	52.1	10.5	4.6	.1	2.17	4.65	5.80	3,075	3,650	4,700	5,075
B	June 19, 1930				97.0	64.3	49.8	11.1	4.0	.5							
11, A	Sept. 24, 1929 [2]	60-70 slow-curing oil and 110-120 M asphaltic emulsion.	(6)	Crusher-run stone, ¾ inch to dust	100.0	36.0	27.4	5.9	5.4	.4	[3] 12.54	[2] 14.67	[3] 14.67	---	---	---	---
A	June 19, 1930				100.0	36.2	22.5	5.2	4.3	.2							
B	Sept. 24, 1929 [2]				100.0	33.8	24.0	4.9	4.6	.2	[3] 14.85	[2] 17.17	[3] 17.38	---	---	---	---
B	June 18, 1930				100.0	34.5	21.0	4.9	3.4	.6							
12, A	Sept. 26, 1929 [2]	60-70 slow-curing oil and 95+ M asphaltic emulsion.	(6)	do	100.0	31.6	22.9	5.4	3.8	.6	[3] 13.60	[2] 15.90	[3] 16.85	---	---	---	---
A	June 18, 1930				100.0	35.3	23.0	6.2	4.8	.8							
B	Sept. 6, 1929 [2]				100.0	43.2	30.5	8.1	4.8	.6	[3] 15.37	[2] 16.59	[3] 17.67	---	---	---	---
B	June 18, 1930				100.0	47.4	32.9	8.1	4.6	2.1							
13	Sept. 30, 1929 [2]	Water and 95+ L asphaltic emulsion.	(6)	do	100.0	37.4	22.6	4.7	1.4	1.0	[3] 45.73	[2] 46.72	[3] 48.26	---	---	---	---
	June 18, 1930				100.0	41.9	25.5	5.1	[5] 2.7	2.1							

[1] Percentage loss based on amount of water and bitumen in the mix.
[2] Sampled during compaction.
[3] Tests on loose samples.
[4] Tested at 60° C.
[5] Includes seal.
[6] See table 1.

TABLE 4.—*Analyses of bituminous materials used on various sections (asphalt emulsions excepted)*

Grade and type of material	110-120 penetration asphalt cut back with kerosene			60-70 slow-curing oil	60-70 slow-curing oil		60-70 slow-curing oil	60-70 slow-curing oil	70-80 slow-curing oil	
How and where used	Mix on secs. 1, 2, and 10			Mix on sec. 3	Mix on secs. 4 and 5		Seal on sec. 5, premix on secs. 11 and 12	Mix on sec. 6	Mix on secs. 7 and 8	
Specific gravity at 25° C	0.970	0.965	0.965	0.968	0.968	0.968	0.969	0.968	0.975	0.979
Flash point, C.O.C., °C	79	80	77	143	142	145	149	142	174	166
Specific viscosity Engler at 50° C	78.9	72.7	81.0	64.2	75.7	79.1	82.5	69.4		
Approximate Saybolt-Furol at 50° C., seconds	315	290	325	255	305	315	330	280		
Specific viscosity Engler at 100° C									9.3	12.1
Float test at 50° C., seconds									32.4	45
Loss 163° C., 5 hours, 50 centimeters, percent	13.28	14.00	13.00	6.5	11.0	10.2	9.5	6.6	1.9	1.9
Float on residue at 50° C., seconds	75.8	89	78	25.2	28.4	28.8	29.7	25.4	40.4	49.6
Loss at 163° C., 5 hours, 20 centimeters, percent	17.39	18.6	17.8	9.2	14.5	14.0	12.5	9.7	2.7	2.8
Float on residue at 50° C., seconds	153.6	207	188	35.8	35.4	34.8	39.6	35.2	41.8	53
Soluble in CS_2, percent	99.79	99.82	99.88	99.79	99.82	99.80	99.82	99.81	99.88	99.82
Organic matter insoluble, percent	.18	.13	.11	.18	.17	.18	.14	.16	.11	.16
Inorganic matter insoluble, percent	.03	.05	.01	.03	.01	.02	.04	.03	.01	.02
Bitumen insoluble in 86° B. naphtha, percent	8.05	8.93	9.71	3.87	3.03	4.17	4.44	4.29	3.61	6.47
Residue of 100 penetration, percent	75.3	76.2	75.7	61.0	60.9	61.7	65.4	61.8	72.7	77.2
Penetration on residue at 25° C., 100 centimeters, 5 seconds	103	112	102	109	104	113	112	89	89	92
Penetration on residue at 0° C. 200 centimeters, 60 seconds	19	25	22	23	20	27	21	19	17	19
Softening point of residue, °C	44.2	44.4	46.2	44.4	42.6	39.8	46.0	45.2	45.6	45.4
Ductility of residue at 25° C., centimeters	110+	110+	110+	110+	110+	110+	87	110+	110+	110+
Ductility of residue at 1.5° C., centimeters	7.0	5.2	4.6	[1] 1.8	7.2	[1] 2.0	[1] 1.6	[1] 2.2	6.0	1.8

Grade and type of material	94+ asphaltic oil cut back with kerosene		50-60 slow-curing oil	110-120 penetration asphalt cut back with kerosene	150-200 penetration asphalt	94+asphaltic oil	110-120 asphalt cut back with naphtha	50-60 slow-curing oil	50-60 slow-curing oil
How and where used	Mix on secs. 9 and 10		Priming on left lane of secs. 14, 15, 16, and 17	Priming on right lane of secs. 14, 15, 16, and 17	Surface treatment on sec. 14	Surface treatment on secs. 15 and 16	Surface treatment on sec. 17	Priming on sec. 18	Priming on secs. 18, 19, 20, and 21
Specific gravity at 25° C	0.971	0.966	0.945	0.943	1.004	1.011	0.958	0.948	0.945
Flash point, C.O.C., °C	88	85	117	68	262	243	38	123	115
Specific viscosity Engler at 50° C	100.2	92.2	18.8	17.2			51.9	20.7	17.6
Approximate Saybolt-Furol at 50° C., seconds	400	370	75	70			240	85	70
Float test at 50° C., seconds					265	248			
Penetration at 25° C., 100 centimeters, 5 seconds					181	199			
Softening point, °C					39.8	40.8			
Ductility at 25° C., centimeters					110+				
Loss 163° C., 5 hours, 50 centimeters, percent	12.6	12.9	8.4	23.1	0.29	0.25	17.7	11.2	8.6
Penetration on residue at 25° C					168	150	124		
Float on residue at 50° C., seconds	114	105	22.8	88				24	21.8
Loss at 163° C., 5 hours, 20 centimeters, percent	15.4	16.0	12.9	30.5			17.8	15.7	12.8
Penetration on residue at 25° C							92		
Float on residue at 50° C., seconds	202	192	49.2	204				45.6	51.2
Soluble in CS_2, percent	99.87	99.90	99.88	99.91	99.92	99.88	99.89	99.88	99.87
Organic matter insoluble, percent	.10	.08	.07	.07	.06	.08	.08	.07	.09
Inorganic matter insoluble, percent	.03	.02	.05	.01	.02	.04	.03	.05	.04
Bitumen insoluble in 86° B. naphtha, percent	9.97	9.85	5.45	13.2	8.08	9.81	7.92	6.14	4.92
Residue of 100 penetration, percent	76.8	76.5	58.8	65.5			78.8	58.8	58.8
Penetration on residue at 25° C. 100 centimeters, 5 seconds	98	87	94	102			91	98	103
Penetration on residue at 0° C. 200 centimeters, 60 seconds	17	16	23					19	21
Softening point of residue, °C	45.4	45	44.8					43	45.3
Ductility of residue at 25° C., centimeters	110+	110	86					110+	110+
Ductility of residue at 1.5° C., centimeters	4.0	4.2	4.0					4.5	5.0

[1] Material did not pull to a thread.

TABLE 5.—*Analyses of typical asphaltic emulsions used on the various sections*

Grade	95+L	95+M	95+L2	94+L2	90-95 L3	110-120 M	Standard	Standard
How and where used	Mix on sec. 13 and seal on secs. 12 and 13	Mix on secs. 11 and 12	Seal on secs. 11, 12, and 13	Surface treatment on sec. 19 and right lane on sec. 18	Surface treatment on left lane sec. 18	Mix on sec. 11	Surface treatment on secs. 20 and 21	Surface treatment on sec. 21
Specific gravity, 25°/25° C	1.008	1.009		1.009	1.006	1.010	1.007	1.011
Specific viscosity, Engler, at 50° C				2.8	2.9	1.9	1.7	2.7
Distillation to 260° C.:								
Water, percent by weight	41.9	40.1	48.4	42.8	42.4	50.9	43.2	42.3
Oil, percent by weight	.1	.1		.1	Trace	.2	Trace	.05
Residue, percent by weight	58.0	59.8	51.6	57.1	57.6	48.9	56.8	57.7
Tests on residue:								
Specific gravity, 25°/25° C	1.012	1.020		1.014	1.009	1.017	1.008	1.012
Penetration at 25° C	126	110	148	202	234	98	142	154
Softening point, °C	41.6	48.2		42.4	35.6	48.8	43.8	44.4
Ductility at 25° C	79	47		110+	81	50	92	110+
Bitumen soluble in CS_2, percent	99.04	94.87		96.67	98.05	94.69	99.00	98.73
Organic matter insoluble, percent	.05	2.54		.37	.55	2.54	.18	.44
Inorganic matter insoluble, percent	.91	2.59		2.96	1.40	2.77	.82	.83

TABLE 6.—*Amounts of bituminous material used on the different road-mix sections (exclusive of seal coat) and the amounts indicated b various formulas*

Section	Calculated amount of bitumen exclusive of solvent and water in mix (percent) [2] [3]	Average amount of bitumen 1 year after construction, by extraction	Amount of bituminous materials required according to various formulas [1]			Remarks on richness of the mix as indicated by service behavior
			Stanton, Calif.	Utah	Wyoming, N. Dak.	
1, A	4.2 [3]	3.3	2.7	3.1	2.9	Slightly lean without seal.
1, B	4.3 [3]	3.6	3.7	4.0	4.1	Do.
1, C	5.5 [3]	3.3	3.7	4.0	4.1	Satisfactory without seal.
2	3.6 [3]	3.6	2.1	2.5	2.1	Rich.
3	4.4	3.8	4.6	4.9	5.2	Satisfactory without seal.
4	5.0	3.1	4.0	4.2	4.3	Do.
5	4.8		4.2	4.5	4.8	Slightly lean without seal.
6	4.2		3.8	4.0	4.1	Very lean. Satisfactory with seal
7	6.1	5.1	4.4	4.5	4.8	Satisfactory.
8	4.0	3.5	2.3	2.8	2.4	Rich.
9	4.2	3.5	4.5	4.8	5.0	Slightly lean without seal.
10	3.5	4.0	3.9	4.2	4.3	Satisfactory without seal.
11	2.6–3.5 emulsion [3] 1.5 slow-curing oil	3.9	3.7	3.8	3.9	Sufficient but poorly distributed.
12	3.3–3.6 emulsion [3] 1.5–2.2 slow-curing oil	4.7	2.8	3.1	2.9	Do.
13	3.5 [3]		2.7	3.0	2.8	Very lean.

[1] These formulas are all based on the division of the aggregate on the no. 10 and no. 200 sieves:

P= Percent of oil required.
a= Percent of aggregate retained on the no. 10 sieve.
b= Percent of aggregate passing to no. 10 and retained on the no. 200 sieve.
c= Percent of aggregate passing the no. 200 sieve.

Stanton, Calif.: $P=0.02a+0.045b+\begin{cases}0.15c \text{ for fine aggregate.}\\ 0.18c \text{ for average aggregate.}\\ 0.20c \text{ for coarse aggregate.}\end{cases}$

Utah: $P=0.02a+0.033b+0.195c+H$ (H is an absorption factor and is usually taken as 0.5).

Wyoming and North Dakota: $P=1.4\ (0.015a+0.03b+0.17c)$.

[2] The percentage of bituminous material by weight were calculated on the basis the specific gravities of the bituminous materials as given in tables 4 and 5 and th following unit weights of loose aggregates:

	Pounds per cubic foot
Gravel	100
Close graded crushed stone	90
Crusher-run stone	85
Open graded crushed stone	80

[3] The quantities of cut back and emulsion have been corrected for solvent or wate using 56 percent of bitumen for the emulsions and 80 percent residual bitumen for th cut backs.

An 8-ton tandem roller was used to obtain final compaction on the road-mixed emulsion sections and cut-back asphalt sections. The sections built with slow-curing oil were not rolled but were compacted entirely by traffic.

Obstructions, as shown in figure 4, A, were devised to guide the traffic so as to compact the full width of the surfacing. These were moved at frequent intervals to distribute traffic as required. The road-mix sections were built in 1929 and their behavior up to the final inspection in October 1932 is discussed in the following pages.

ROAD-MIX SECTIONS DESCRIBED IN DETAIL

Section 1.—The section consisted of a road-mix with medium-curing cut-back asphalt. The mix was composed of crushed rock and 110–120 penetration asphalt cut back with kerosene. The section was divided into three parts in order to investigate the use of differently graded aggregates and different amounts of binder.

Section 1–A, at eastern end of the project, was 639 feet long and was surfaced with crusher-run stone (three-fourths inch to dust) mixed with 1.71 gallons per square yard of cut-back asphalt. The aggregate contained 0.5 percent moisture and the mechanical analysis was as follows:

Passing—	*Percent*
¾-inch screen	100. 0
½-inch screen	76. 5
No. 3 sieve	46. 0
No. 10 sieve	13. 0
No. 200 sieve	2. 5

Section 1–B was 660 feet long and was surfaced with crusher-run stone (three-fourths inch to dust) with an admixture of fines to increase the percentage of dust and was mixed with 1.92 gallons per square yard of cut-back asphalt of the same grade as used on section 1–A. The aggregate contained 2.5 percent moisture and the mechanical analysis was as follows:

Passing—	*Percen*
¾-inch screen	100.
½-inch screen	72.
No. 3 sieve	49.
No. 10 sieve	28.
No. 200 sieve	7.

Section 1–C was 1,320 feet in length and was identical with section 1–B as to aggregate and type o binder. The section was mixed at the same time a 1–B using 2.26 gallons per square yard of the cut-bacl material. The mixed material was spread and compacted by traffic for 8 days. A wide spread in bituminous content was desired betwen sections 1–C anc the other sections and at this time it was evident tha a greater amount of bituminous material could be usec without causing instability. The section was therefore scarified and remixed with the addition of 0.2 gallon per square yard.

No difficulty was encountered in handling, applying or mixing the cut-back material. Less mixing seemec to be necessary than with the slow-curing oils of simila viscosity. The mixture on sections 1–B and 1–C which contained added fines, compacted and bondec much more quickly under traffic than did section 1–A where fines were not added. The edges of these sections were rolled about 10 days after construction anc were greatly improved in appearance. By that tim the traveled portion of the roadway had compactec to such an extent that rolling of this portion was no considered necessary.

Cost of section 1:
1–A—46.94 cents per square yard or $5,507 per mil
1–B—51.18 cents per square yard or $6,005 per mile.
1–C—58.57 cents per square yard or $6,872 per mile.

All three sections were in good condition whe inspected 3 years after the construction. The surface were free from rich areas such as developed extensivel on some of the slow-curing oil sections. Sectio 1–C which had the highest asphalt content, retaine

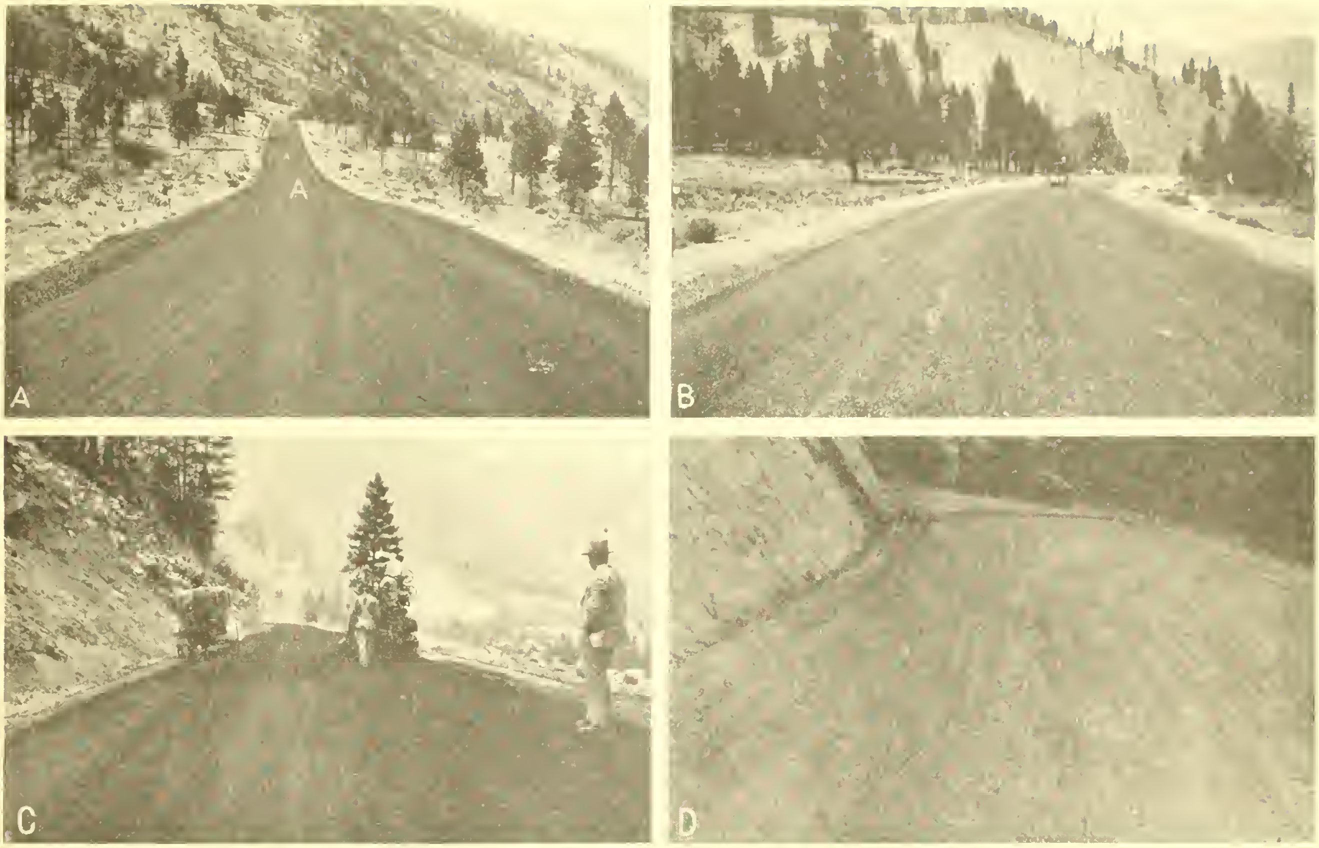

FIGURE 4.—A, OBSTRUCTIONS USED TO GUIDE TRAFFIC SO AS TO COMPACT ENTIRE SURFACE; B, THE RELATIVELY QUICK-BREAKING EMULSION USED ON SECTIONS 11 AND 12 PRODUCED A MIXTURE WHICH WAS DIFFICULT TO COMPACT; C, A UNIFORM MIX WHICH COMPACTED READILY WAS OBTAINED ON SECTION 13 BY THE USE OF A SLOW-BREAKING EMULSION; D, THE LEANNESS OF SECTION 13 RESULTED IN RAVELING WHICH CONTINUED UNTIL THE SURFACE WAS SEALED.

the most wear-resistant surface. Sections 1–B and 1–A began to show slight signs of surface raveling during 1932 and were given a light seal treatment of 0.15 gallon of 90–95 asphaltic oil applied hot and a cover of 11 pounds of ¼-to ⅛-inch crushed stone per square yard.

Except for the seal treatment, the only maintenance required had been the skin patching of a few small areas on section 1–A where the surface cracked due to movement in the subgrade.

Section 2.—The section consisted of a road-mix of cut-back asphalt and open graded crushed-stone aggregate. The aggregate was ¾- to ⅛-inch crushed stone bound with 1.4 gallons per square yard of 110–120 penetration asphalt cut back with kerosene.

The moisture content of the aggregate was 0.25 percent and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	100.0	100.0
½-inch screen	86.0	79.5
No. 3 sieve	55.5	41.0
No. 10 sieve	2.0	1.0
No. 200 sieve	25	0

Mixing was completed on this section with considerably less effort than on section 1 where the aggregate included fines. The cut-back asphalt readily and thoroughly coated all of the stone particles. The mix, however, compacted and bonded slowly with the result that for several days some aggregate was displaced by traffic. Less displacement of aggregate would probably have occurred, not only on this section but also on section 1, had the mix been allowed to cure until somewhat tacky before being spread and compacted.

The cost of the surface was 66.50 cents per square yard, or $7,802 per mile.

As a result of the use of the medium-curing type of cut-back asphalt, instead of the rapid-curing type which would have been better suited to the open-graded aggregate, the mix did not develop high stability until about 2 years after construction. The surface of this section remained in excellent condition although the indications were that it was somewhat rich when constructed.

Probably a better design for this section would have been a leaner mix with a light seal treatment to provide the necessary resistance to displacement. Maintenance had been limited to a few small skin patches where the surface cracked or slight surface depressions had developed.

Section 3.—A slow-curing oil was mixed with a close-graded gravel. The surface was composed of 25-percent uncrushed, washed gravel 1 to ⅛ inch in size and 75 percent of crushed gravel 9/16 inch to dust, bound with a 60–70 oil applied at the rate of 1.70 gallons per square yard. The moisture content of the aggregate was 3 percent, and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1¼-inch screen	100.0	100.0
1-inch screen	98.0	97.0
¾-inch screen	91.0	88.0
½-inch screen	78.0	75.0
No. 3 sieve	62.0	60.0
No. 10 sieve	40.0	41.5
No. 200 sieve	11.0	11.5

The materials were mixed readily and the mixture, on being spread, appeared quite dark in color for a typical oil-mix. It seemed to compact more rapidly under traffic than did the other oil and crushed-stone mixes. The mix appeared richer than the stone mixes having the same grading of aggregate and amount of oil This was probably due to the relatively high percentage of moisture in the aggregate.

The cost of the surface was 69.68 cents per square yard or $8,175 per mile. Its high cost was due largely to the use of gravel aggregate which was shipped by rail.

The action of moisture on the mix seems to have been more pronounced than on section 4 where crushed stone aggregate was used. The surface, except for a small area on the west end where drainage and subgrade conditions were bad, remained generally hard and stable until the spring of 1931 when it softened quite generally, necessitating scarifying and remixing of about 500 lineal feet on the east end and 700 feet on the west end.

It should be noted that the portions which failed first on this section, as well as on section 4, were those where the mix appeared somewhat rich in oil at the time of construction. Poor drainage and subgrade conditions, which prevailed on several small portions of the section, also seemed to greatly hasten the softening of the surface.

During the summer of 1932 a seal treatment of one-fourth gallon of 90–95 hot asphaltic oil and a cover of 16.5 pounds of one-fourth- to one-eighth-inch crushed stone was added to several portions of the section on which the mix had not softened appreciably. The area treated was mostly over fills and totaled 3,111 square yards, or slightly more than half of the entire section.

Section 4.—A slow-curing oil was mixed with a close-graded crushed stone. The mix was composed of crusher-run stone, three-fourths inch to dust, with fines added as filler, and 60–70 oil applied at the rate of 1.78 gallons per square yard. The aggregate contained from 2.75 to 3 percent of moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	94.0	92.0
½-inch screen	79.5	79.0
No. 3 sieve	64.0	64.0
No. 10 sieve	37.0	38.0
No. 200 sieve	7.5	7.5

Sections 4, 5, and 6 were designed to have practically identical mixes except as to percentage of oil used. Sections 5 and 6, however, were surface treated while section 4 was not.

The cost of the surface was 44.57 cents per square yard or $5,229 per mile.

The surface remained in good condition generally. The mix appeared somewhat lean at the time of construction but no appreciable raveling occurred. Softening of the mix did not develop to the extent that it did on section 3 although it was necessary to scarify and remix about 500 feet on the east end during the summer of 1931. This portion was almost entirely in a cut where the drainage and subgrade were not satisfactory. A seal treatment, similar to that used on section 3, was applied in 1932 to several short portions totaling 666 square yards where the surface was beginning to ravel, particularly along the edges.

Section 5.—A slow-curing oil was mixed with a close-graded crushed stone and followed with a light seal. The mix was composed of crusher-run stone, three-fourths inch to dust, with fines added and 1.7 gallons of 60–70 oil. After compaction a light seal treatment of 60–70 oil and a cover of ¼- to ⅛-inch screenings was applied. The aggregate contained from 2.75 to 3.25 percent of moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	95.0	93.0
½-inch screen	72.0	80.0
No. 3 sieve	54.0	69.0
No. 10 sieve	33.0	44.0
No. 200 sieve	9.0	9.25

After the surface had been down about 35 days and had become thoroughly compacted, it was swept clean with a power broom and a light seal treatment of 60–70 oil was applied. The oil was heated to about 140° F. and was applied at the rate of 0.17 gallon per square yard on the right half of the surface and at the rate of 0.10 gallon on the left half. A cover of about 19 pounds of ¼- to ⅛-inch screenings was then spread, following which the surface was rolled with an 8-ton tandem roller. The major portion of this cover material was thrown to the sides by traffic due to the inability of the slow-curing oil to hold the aggregate cover.

The appearance of the surface before applying the seal treatment seemed to indicate a slight deficiency in oil which would probably have resulted in some raveling had not the seal treatment been applied. The principal effect of the treatment was to enrich the surface and make it more resistant to the wear of traffic. The cost of the surface was 52.03 cents per square yard or $6,105 per mile.

In general, this section had remained in better condition than either sections 3 or 4. Although there were some indications of softening of the mix in a few small local areas, failures did not develop sufficiently to affect the generally good condition of the surface.

Maintenance, except for some skin patching, had consisted of scarifying and remixing in the summer of 1931 of about 200 feet of surface on the east end and the application of an additional seal treatment during the summer of 1932 to 751 square yards of the surface which was beginning to show some signs of wear. This treatment was similar to that applied to sections 3 and 4 except that one-fourth gallon of bituminous material and 16.4 pounds of cover were used per square yard.

Section 6.—The section consisted of slow-curing oil mixed with crushed stone with a light surface treatment. The mix was composed of crushed stone, three-fourths inch to dust, without the addition of fines, and 60–70 oil at the rate of 1.40 gallons per square yard. A light surface treatment was applied late in the fall. The aggregate contained 2.5 percent moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	96.0	94.0
½-inch screen	85.5	81.3
No. 3 sieve	71.5	64.5
No. 10 sieve	38.2	34.1
No. 200 sieve	6.8	5.8

The mix in this experiment was purposely made lean as a surface treatment was to be applied later. Some raveling and pot-holing occurred during the period of about 2 months which intervened between the placing of the mix and the applying of the surface treatment and it is doubtful if the untreated oil-mix surface could have gone through the first winter without considerable failure.

Previous to the application of the surface treatment the surface was swept and all holes patched. A 94+ grade of asphaltic oil heated to about 400° F. was applied at the rate of 0.28 gallon on the right half of the roadway and 0.22 gallon on the left half. It was immediately covered with 18.7 pounds per square yard of ½- to ⅛-inch stone and then rolled. A different amount of oil was used on each half of the road width in order to obtain information as to the most economical amount to use. As the treatment was not applied until late in the fall, cold weather prevented complete cementing of the cover stone and, as a result, some of the aggregate was displaced by traffic. It was not until the following summer that the oil warmed sufficiently to come up through the stone and at that time some additional cover had to be added to stop bleeding.

The cost of the mix and surface treatment was 47.17 cents per square yard or $5,534 per mile. The mix alone cost 37.88 cents per square yard or $4,444 per mile.

This section had remained in excellent condition. The surface was free from soft spots such as occurred on some of the other sections with light oil mixes. Such little maintenance as had been required consisted of applying a few small seal patches.

Section 7.—A slow-curing oil was mixed with a close-graded crushed stone. The mix was composed of crushed stone, three-fourths inch to dust with which fines were added, and 70–80 oil at the rate of 2.16 gallons per square yard. The aggregate contained from 1.5 to 3 percent moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	100.0	100.0
½-inch screen	79.5	84.5
No 3 sieve	65.0	70.0
No. 10 sieve	45.5	41.0
No. 200 sieve	11.0	6.5

Considerable difficulty was encountered in mixing the 70–80 oil because of cold weather during construction. The quantity of oil first tried was 1.93 gallons per square yard. Since this did not appear to be sufficient an additional 0.23 gallon was used. The mix compacted rapidly and developed an excellent nonskid surface texture. The oil seemed to have better adhesive properties than did the 60–70 oil but was less adhesive than the cut-back asphalts.

The cost of the mix surface was 47.82 cents per square yard or $5,611 per mile.

Softening of the mix developed early on about 600 feet on the west end and on about 200 feet on the east end. These portions appeared rich at the time of construction and the soil and drainage were not as satisfactory as on the other portions of the section. The soft places were scarified and remixed during 1931. In 1932 a seal treatment, similar to that used on a portion of section 5, was applied to 265 lineal feet where the surface was beginning to wear. The section was in good condition at the time of the last inspection.

Section 8.—A slow-curing oil was mixed with an open-graded crushed stone. The mix was composed of crushed stone, three-fourths to one-eighth inch in size and a 70–80 oil at the rate of 1.24 gallons per square yard. The aggregate contained from 0.2 to 3.5 percent moisture and mechanical analyses were as follows:

	Sample A	Sample B
Passing-	*Percent*	*Percent*
¾-inch screen	100.0	100.0
½-inch screen	84.9	83.9
No. 3 sieve	52.0	48.2
No. 10 sieve	7.0	5.0
No. 200 sieve	1.0	1.0

The material was mixed very quickly and was allowed to remain in the windrows for several days before it was spread. Compaction took place slowly and there was appreciable displacement of stone under traffic for several days during the early compaction. Rolling was finally resorted to and aided considerably in compressing and smoothing the loose surface material. The surface obtained was more open than was desired but, in accordance with the original plan, it was not given a seal. The early behavior of this section and the difficulty in compaction was similar to that experienced on section 2 where a 110–120 penetration asphalt cut back with kerosene was used. The cost of the surface was 59.55 cents per square yard, or $6,987 per mile.

In the spring following construction this section failed by rutting extensively under the truck traffic incident to the construction of sections in 1930. Although the west half of the section, which was in a cut where the subgrade soil and drainage were bad, failed first and most extensively, it was evident, even on the good subgrade, that the mix lacked sufficient stability. The section was considered unsatisfactory and it was discontinued as an experiment during the fall of 1930.

Section 9.—A close-graded crushed stone was mixed with a kerosene cut-back. The mix was composed of crushed stone, three-fourth inch to dust, with muck-sand filler added, and 94+ asphaltic oil cut back with kerosene and applied at the rate of 1.86 gallons per square yard. The aggregate contained from 1 to 2 percent moisture and mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	98.0	96.5
½-inch screen	82.0	83.5
No. 3 sieve	67.5	70.0
No. 10 sieve	41.0	48.5
No. 200 sieve	9.0	11.0

On account of a delay in shipment of a portion of the cut-back material for this section, several days intervened between the mixing of the two windrows. The south windrow was mixed and left to cure for 4 days before being combined with the north windrow. Such slight hardening as occurred in the mix did not seem to add difficulty to the final processing or compaction and seemed to aid in obtaining early compaction with much less raveling under traffic. The section was rolled during the early compaction. The cost of the surface was 50.81 cents per square yard, or $5,962 per mile.

This section had remained in excellent condition. Practically no maintenance had been required although it appeared that a light seal coat would probably be beneficial. The surface was nonskid, uniform in color, and free from soft spots.

Section 10.—A kerosene cut-back and was mixed with close-graded gravel. The mix was composed of a close-graded gravel, such as was used on section 3, containing sufficient fines without the addition of filler and a 94+ asphaltic oil cut back with kerosene. A small amount of cut-back asphalt of 110–120 penetration was also used. The aggregate, containing 0.5 to 0.6 percent moisture, was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	93.0	99.0
¾-inch screen	81.0	85.5
½-inch screen	63.2	77.5
No. 3 sieve	56.4	63.0
No. 10 sieve	36.7	37.5
No. 200 sieve	7.5	6.8

The asphaltic material used in the mix consisted of 1.58 gallons of 94+ cut back and 0.14 gallon of 110–120 cut back, the latter being added to make up for the shortage of the former.

The material for the left half of the road was processed and windrowed 5 days before processing the other half. Four days after mixing the second windrow the two were mixed together and spread. The surface was rolled on the following day. Here, as on section 9, the short period of curing seemed to have been of considerable benefit as the mixture compacted quickly and a smooth hard surface was obtained.

The total cost of the surface was 71.19 cents per square yard or $8,353 per mile. The high cost of this experiment is due largely to the freight charges on the gravel, which was shipped a long distance by rail.

The surface was in excellent condition except for 200 feet on the west end where bad subgrade and drainage conditions had resulted in some displacement and cracking. The surface appeared much richer than that of section 9 and was less nonskid. Except for some patching on the west end and at a few locations on the edges, no maintenance had been required.

Section 11.—This section was road-mix, composed of asphaltic emulsion and crusher-run stone, three-fourths inch to dust. The aggregate was first mixed with 0.48 gallon of 60–70 oil, after which 1.54 gallons of 110–120 M asphaltic emulsion was applied and mixed. The portion between stations 361+39 and 353+59 was enriched by adding 0.49 gallon of 95+ M asphaltic emulsion.

A seal treatment consisting of 0.30 gallon of a mixture of 95+ M and 95+ L emulsions and about 11 pounds of ¼- to ⅛-inch cover stone was applied to the portions between stations 361+39 and 357+49 and between 349+69 and the west end of the section. The remaining portion of the section was left until the following summer when it also was sealed, using 0.18 gallon of 95+ L2 asphaltic emulsion on the left half of the roadway and 0.17 gallon on the right half, with a cover of 11 pounds per square yard of ½- to ⅛-inch stone chips. All the seal treatments were rolled immediately following the application of the cover stone.

The aggregate contained 1.5 percent of moisture and was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	100.0	95.0
½-inch screen	85.5	82.0
No. 3 sieve	75.5	70.0
No. 10 sieve	49.0	37.0
No. 200 sieve	4.5	5.0

The results obtained in the mixing operation were not very satisfactory. The emulsion,[1] which was not a true mixing emulsion, broke and became viscous so quickly that mixing was difficult. Instead of coating all of the particles uniformly, as did the other types of bituminous materials, this relatively quick-breaking emulsion had a decided tendency to form the finer particles in balls, leaving the larger particles practically uncoated. When the materials had been processed as well as possible, the mix was spread and rolled but it did not bond well and displaced considerably under traffic. It was decided to enrich the east half from stations 361+39 to 353+59 by remixing with the addition of 0.49 gallon of the 95+ M emulsion. This portion bonded somewhat more readily than before although considerable displacement of aggregate by traffic occurred for several days. An attempt was made to consolidate the mix by rolling intermittently for several days. Consolidation was finally accomplished to a fair degree, the finer particles being pressed around and interlocking with the larger poorly-coated particles.

Although the manufacturers of the emulsion contended, and it was generally agreed at the time of construction, that the emulsion-mix sections would require a seal treatment for best results, it was decided to seal only a portion of each section immediately. However, in order to prevent extensive deterioration of the unsealed portions, which were on relatively poor subgrade, they were given a seal treatment during the following summer.

The cost of the mix and seal was 64.46 cents per square yard or $7,563 per mile.

Section 12.—A road-mix was placed consisting of an asphaltic emulsion and crusher-run stone. The crusher-run stone ranged from three-fourths inch to dust. The aggregate was first mixed with 60–70 oil at the rate of 0.48 gallon between stations 345+79 and 343+79, and 0.70 gallon on the remainder of the section, following which 1.84 gallons of emulsified asphaltic oil of the 95+ M grade was applied and mixed. The portion between stations 345+79 and 343+79 was enriched by adding 0.23 gallon of 110–120 M asphaltic emulsion.

The portions between stations 345+79 and 340+89 and from station 331+09 to the end of the section were sealed shortly after the compaction of the surface. On the first portion 0.3 gallon of a mixture of 95+ M and 95+ L emulsion was applied, while on the latter portion the same amount of the 95+ L grade emulsion alone was used. About 11 pounds per square yard of ¼- to ⅛-inch stone screenings were used in covering both portions. As in the case of section 11, the portion left unsealed at the time of construction was given a seal treatment during the following summer. In this treatment 0.18 gallon of 95+ L2 emulsion was applied to the left half of the roadway and 0.21 gallon to the right half. Both portions were covered with 11 pounds per square yard of ½- to ⅛-inch stone screenings and rolled.

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[1] The demulsibility of this emulsion, using 50 cubic centimeters 0.10N. calcium chloride, was 100 percent compared with present A. S. T. M. requirement of a maximum of 30 percent.

The aggregate used on this section contained 1 to 1.2 percent moisture and was analyzed as follows:

	Sample A	Sample B
	Percent	*Percent*
Passing		
1-inch screen	100.0	100.0
¾-inch screen	92.0	95.0
½-inch screen	72.5	74.5
No. 3 sieve	49.0	44.0
No. 10 sieve	14.0	26.0
No. 200 sieve	2.0	2.7

As in the case of section 11, difficulty was encountered in mixing and compacting and, during the extended period of compaction, considerable aggregate was displaced by traffic. This condition is illustrated in figure 4, *B*. After the mix had hardened, about half the section was sealed, the remaining portion being left until the following summer when the sealed and unsealed surfaces had about the same appearance as the corresponding parts of section 11, except that the unsealed surface was slightly better bonded than that on the leaner portion of section 11.

The cost of the mix and seal was 64.62 cents per square yard or $7,582 per mile.

Section 13. On this section an asphaltic emulsion was mixed with crusher-run stone ranging from three-fourths inch to dust. The aggregate was primed and mixed with 2.23 gallons of water. Following this, asphaltic emulsion 95+ L was applied at the rate of 2 gallons per square yard and mixed. Figure 4, *C* illustrates the mix.

The easterly portion, stations 326+19 to 311+23 was sealed after compaction of the mix, using 0.3 gallon of 95+ L emulsion and covered with about 11 pounds per square yard of ¼- to ⅛-inch screenings. The remaining portion was given a seal treatment during the following summer, consisting of 95+ L2 emulsion applied at the rate of 0.18 gallon on the left half and 0.21 gallon on the right half and covered with 13 pounds per square yard of ½- to ⅛-inch screenings on the left half and 11 pounds per square yard on the right. Raveling resulting from the leanness of the mix is illustrated in figure 4, *D*.

The aggregate used on this section contained from 5 to 7.5 percent moisture and was analyzed as follows:

	Sample A	Sample B
	Percent	*Percent*
Passing—		
1-inch screen	100.0	100.0
¾-inch screen	89.0	93.0
½-inch screen	69.0	70.5
No. 3 sieve	52.0	48.0
No. 10 sieve	24.0	21.0
No. 200 sieve	1.0	1.5

The cost of the mix and seal was 67.29 cents per square yard or $7,895 per mile.

Although the subgrade was variable and of inferior quality on portions of the section, certain types of failure occurred in the emulsion mixtures which seemed to be due to the character of the mix rather than to that of the subgrade.

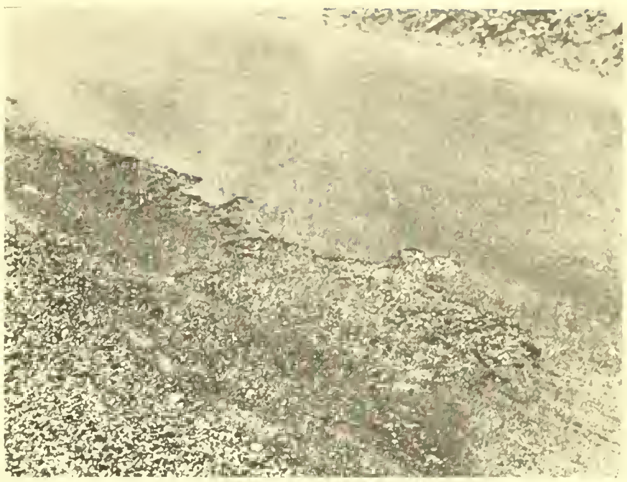

FIGURE 5.—TYPICAL CRACKING AND PEELING WHICH OCCURRED DURING THE SPRING ON PORTIONS OF SECTIONS 11 AND 12, DUE TO THE BAD SUBGRADE AND POOR DRAINAGE IN THE DITCHES.

Where the worst subgrade conditions existed, it was necessary to remove the defective subgrade to a depth varying from a few inches to 18 inches or more and to do extensive patching during the early summer of 1931. This work put the surfaces in fairly good condition and it was thought that the sections would go through the next winter satisfactorily. However, further failure of the subgrade occurred and additional extensive repairs were again necessary during the spring of 1932.

MORE IMPORTANT FACTORS AFFECTING THE BEHAVIOR OF THE ROAD-MIX SECTIONS DISCUSSED

Of the factors affecting the service behavior of the oil-mix type of surfacing as built in the Western States, moisture is probably the most important. Moisture in the aggregate at the time of mixing, moisture seeping into the surface from the top and, perhaps most important of all, moisture entering the surface from the subgrade, must all be considered as potential causes of failure.

In these experiments the most noticeable result of the effect of moisture was the development of areas having the appearance of excessive richness in bitumen. On these areas the mat became so soft and unstable as to require scarifying and remixing. The time intervening before this unsatisfactory condition developed varied from a short time after construction to a period of 2 years. Subgrade water which entered the mixture from below was responsible for most of the failures of this type.

Examination of the mat from areas affected by moisture in otherwise good sections indicated that water, in rising through the mix toward the surface, had apparently carried with it an appreciable amount of oil.

The richer mixes seemed to lose stability earlier and to a greater extent than did the leaner ones. Section 7 furnishes a good example of the comparative effect of subgrade moisture on rich and lean mixes. On this section drainage and subgrade conditions were fairly uniform but the west half of the section, which was comparatively rich, softened, became unstable and had to be scarified and remixed in 1931, while the east portion, except for a small area at the beginning of the section, has remained in excellent condition. Analyses of mat samples taken from the east and west portions show the former to contain approximately 25 percent more bituminous material than the latter.

Softening of the mat occurred most generally in cuts where drainage conditions were least satisfactory. Section 4 remained in good condition except for a short portion at the east end which was in a cut with poor drainage and subgrade. The mat on this portion of the section softened and was scarified and remixed in 1931.

Section 3, on which gravel was used, softened more extensively than did section 4, on which crushed stone was used. Due to the smooth, round character of the gravel particles, the stability of the gravel is apparently reduced more quickly than that of the rough, angular crushed material when an excess amount of water is present in the mix.

The mix on section 5, which appeared somewhat lean and was lightly sealed with the same oil used in the mix, was affected by water to a much less degree than either section 3 or 4. Only a few small areas of its surface had softened. The seal coat provided an excellent, wear-resistant surface on this section which, due to its leanness, would otherwise undoubtedly have failed by raveling. It is believed, however, that its resistance to loss of stability has been due largely to the leanness of the mix rather than to the seal treatment.

On section 6 the mix was very lean, appearing to be much more so than that on section 5, and the surface was sealed with a soft grade of asphalt. This combination of a lean mix with an asphalt seal coat provided an excellent surface and there were no indications that the mix had softened because of subgrade moisture. The behavior of sections 5 and 6 in contrast to that of the richer unsealed sections, particularly in their resistance to the action of moisture, suggest the possible advantage of using a lean mix with a wear resistant surface treatment, particularly where moisture conditions are unfavorable.

The belief that bituminous materials of high viscosity offer more resistance to the effect of moisture on this type of construction than materials of lower viscosity has led to the use of more viscous materials. The effect of the viscosity of the slow-curing oils on their resistance to moisture was not studied in this investigation, but the exceptionally good condition of section 7 on which the more viscous 70–80 oil was used tends to substantiate the opinion regarding the advantage of the heavier oils. The water-resistant properties of the asphaltic cut-back materials are also well illustrated by the behavior of the road-mix sections in which these materials were used. These surfaces continued in good condition, uniform in color, and free from any indication of softening or lack of stability.

GRADING OF AGGREGATE IMPORTANT IN DESIGNING MIXTURES

The grading of the aggregate is important in designing all types of bituminous mixes and is particularly so in designing those types of road-mix in which the bituminous materials used may not compensate for a possible lack of stability in the aggregate. Obviously, if the aggregate does not possess inherent stability it must be supplied by the bituminous material. Conversely, if the aggregate has this property it need not necessarily be characteristic of the bituminous material. Satisfactory stability was obtained on all the road-oil-mix sections where the aggregate was close-graded (from 5.8 to 11.5 percent of dust), although the bituminous material used with it had relatively little cementing value.

Sections 2 and 8 were built with open-graded crushed-stone aggregate ranging from three-fourths to one-eighth inch. A medium-curing kerosene cut back was used on section 2 and a 70–80 slow-curing oil on section 8. On the former section the mix remained plastic for a long time after construction, during this time it seemed on the verge of failure. However, it gradually hardened and in time its condition materially improved. The behavior of this section conforms with experience on other projects where similar medium-curing cut-back materials were used, in that satisfactory stability of the mix developed only after a considerable period of time during which an appreciable amount of volatile material evaporated resulting in greater viscosity in the remaining bituminous material which enabled it to furnish the stability lacking in the aggregate.

Section 8, on which the 70–80 slow-curing oil was used with open-graded aggregate, lacked stability and failed early since the oil was not of a type which hardened so as to provide the stability lacking in the aggregate.

It is apparent that aggregate should be closely graded, contain an appreciable amount of fine material, and have high inherent stability if it is to be used with slow-curing or medium-curing asphaltic materials. The fine particles, particularly that portion of the aggregate passing the no. 200 sieve, seem to stiffen the bituminous material and provide the necessary early stability. The mix on section 2, which contained no fines, displaced under traffic for a long time after construction. Although it finally developed a well-bonded and stable surface the early behavior was not satisfactory, due to the slow development of cohesive properties in the binder.

The exact amounts of fines which should be present when slow-curing, medium-curing, or rapid-curing materials are used cannot be stated definitely. Experience indicates that in constructing road mixes with average aggregates of open grading, rapid-curing materials should be used and that, in general, slow-curing or medium-curing materials should not be used when the dust content of the aggregate is less than approximately 5 percent.

Sections 2 and 8 are typical examples of surfaces containing open aggregates where better results would have been obtained had a more rapid-curing binder been used.

AMOUNT OF SLOW-CURING OIL REQUIRED MAY BE DETERMINED SATISFACTORILY WITH FORMULAS

The subgrade soils on sections 1 to 13, as shown in table 2, include the A–2 (mostly plastic), the A–4, and A–7 types. The A–2 plastic type predominates except on sections 11, 12, and 13. The more unfavorable A–4 and A–7 types comprise the soil on these three sections and were also found in the deep cuts and on other short portions of some of the other sections.

Failures of the surface due to the subgrade were confined almost entirely to those portions overlying A–4 and A–7 soils. The characteristic tendency of the A–4 soils to flow under load was reflected in the behavior of the surface, which failed by settlement and cracking (fig. 5). This type of surface failure was extensive on section 11.

The A–7 soils, which are elastic when loaded, caused cracking without appreciable displacement of the surface. Failures of this type occurred extensively on section 12.

The data on laboratory curing and stability tests made on the material from the various mixtures passing no. 10 sieve, and presented in table 3, give some indication of the degree of curing which might occur in mixed surfaces containing oils and cut backs. It also illustrates the gain in the stability of the fine portion of the mixtures which accompanies the loss of volatile constituents. The tests reported show high stability values indicating that the inherent stability of the fine portion of these road-mixes was high. Gains in stability corresponding to a given loss of volatile matter were substantially greater for the cut-back mixtures than for the slow-curing oils.

The comparatively low total oven losses of volatile matter for the cut-back mixes from sections 9 and 10 indicates that considerable more volatile matter had gone off during the construction operation than on sections 1 and 2. This explains the better early behavior of sections 9 and 10 as compared with sections 1 and 2 and shows the necessity of obtaining an appreciable loss of the solvent (in cut-back materials) before final compaction of the mix.

A comparison of the amount of bituminous materials used with that shown to be required by several formulas, together with comments as to the sufficiency of the amounts used as indicated by service behavior, are given in table 6. In general, the behavior of the sections indicates that the amounts of slow-curing oil required for close-graded aggregates may be determined satisfactorily by means of one of several formulas now in use. The results of these experiments, however, as well as observations on other projects, indicate that where very heavy slow-curing oils and cut backs which produce heavy residues in the road surface are used it may be advantageous to apply greater quantities than called for by the formulas.

Sections 11, 12, and 13, on which asphaltic emulsions were used, were of a more highly experimental character at the time of construction than the remainder of the sections. Little experience had been had with this type of material and little information was available relative to its behavior during construction or as to the proper amount of the material to use under given conditions. Practically all details therefore were experimental and with the complication of inferior subgrade conditions, the results were not very satisfactory.

Considerable difficulty was encountered in mixing sections 11 and 12. The emulsions broke during the mixing operation, balled with the fine particles of aggregate and produced an apparently lean, nonuniform mix which was harsh and very open and in which the coarse particles were very poorly coated with bitumen. On the unsealed portions, the open and poorly bonded surface cracked extensively, especially during the spring season when the subgrade was least stable.

The emulsion on section 13 had a slower break than that used on sections 11 and 12 as indicated during the mixing operation. The fines did not segregate and ball, the coarser particles were well coated and the mixture obtained was uniform and of a close texture. The appearance of the mix on section 13, as compared to that of sections 11 and 12 at the time of construction, is shown by figure 4, *B*, and 4, *C*.

The raveling which occurred on the unsealed portions of section 13 appears to have been caused by insufficient bitumen rather than by the character of the emulsion. As shown in table 3, there was only 1.4 percent bitumen in the mix, and the total amount, including the seal, was 2.7 percent. Figure 4, *D*, illustrates the tendency of the surface to ravel before being surface-treated. A further comparison of the quantity of bitumen, including the admixed oil used in the mix on sections 11, 12, and 13, is obtained by deducting the water content of the emulsions as given in table 5 from the total amounts used. This shows that approximately 1.2 to 1.5 gallons of bitumen per square yard were used in the mix on section 11, 1.8 gallons on section 12, and only 1.2 gallons on section 13.

Since these sections were built, considerable progress has been made in the development of methods of manufacture and handling of this type of material and, without doubt, most of the construction difficulties encountered on these experimental sections can, to a large extent, now be avoided.

VARIOUS TYPES OF SURFACE TREATMENT APPLIED TO CRUSHED-ROCK BASE

A 3-inch compacted base course for the surface treatments, sections 14 to 21, inclusive, was built in the fall of 1929. This consisted of crusher-run stone, three-fourths inch to dust, to which 10 to 15 percent of local clay and silt binder was added. Early snow and freezing weather made it impossible to thoroughly shape and consolidate the base course so that it was necessary to continue this work during the following spring.

Due to the unusually dry weather during the early summer, much of the base material was whipped off by traffic, the final thickness of the base course being thus reduced to between 2 and 2½ inches instead of 3 inches as planned.

Immediately prior to application of the surface treatments, the base was lightly scarified, watered, and bladed. This work was often done during the night preceding application of the prime coat to avoid, so far as possible, damage from traffic between the final shaping of the base and the application of the prime treatment. The base was swept and this was followed immediately by the prime coat. Figure 6, *A*, shows the sweeping operation.

A typical grading of the aggregate used in the base course was as follows:

Passing—	*Percent*
1-inch screen	99. 6
¾-inch screen	95. 9
½-inch screen	80. 6
No. 3 sieve	68. 9
No. 10 sieve	38. 7
No. 200 sieve	10. 2

Details concerning the various sections are given in table 7. A prime treatment was applied to all of the sections. On the right half of sections 14 to 17, inclusive, a 110–120 penetration asphalt cut-back with kerosene was used, while on the left half of these four and on the remaining sections a 50–60 penetration slow-curing oil was used.

The prime coat was applied to one-half the road width and the material allowed to penetrate and dry for about 2 days, after which it was opened to traffic while the other side was similarly treated. Wet areas remaining at the end of the 2-day drying period were blotted with stone chips, one-eighth inch to dust. The cut-back asphalt penetrated to an average depth of three-eighths inch and the slow-curing oil to about one-half inch. The former material produced a tougher, better bonded and more wear-resistant surface than did the oil. Failures did not develop in the cut-back-primed surface, but considerable breaking and scaling occurred where the light oil was used. This tendency of the oil-primed surface to break and ravel is illustrated in figure 6, *B*.

Where raveling occurred in the primed base, the holes were swept clean of dust, sprayed lightly with a slow-curing oil and then filled with crushed rock, three-fourths inch to dust in size.

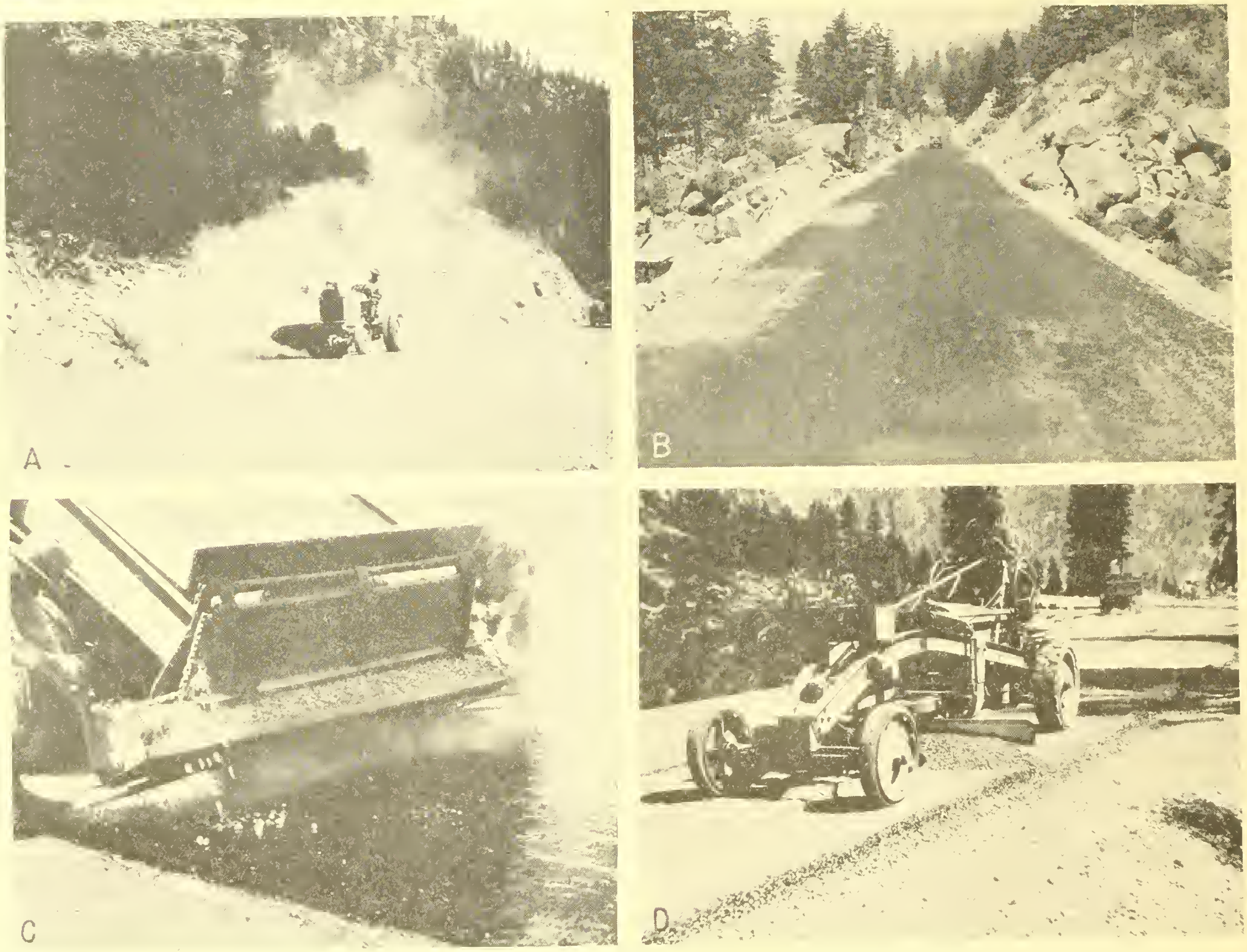

Figure 6.—A, Sweeping Base Before Priming; B, Surfaces Primed with Slow-Curing Oil Broke in Many Places and Required Considerable Repairing before Applying the Surface Treatment; C, Spreading Stone with Boxes Attached to Trucks; D, Equipment Used to Lightly Manipulate and Spread the Cover Stone.

Both light and heavy types of surface treatments involving several types and grades of bituminous materials were used. To facilitate their application, all the bituminous materials, including the emulsion, were warmed.

The crushed stone was loaded from cars or stock piles with a truck crane fitted with a ½-cubic-yard clamshell bucket. Three- and four-cubic-yard dump trucks were used for hauling and spreader boxes were used for spreading. Figures 6 and 7 illustrate the spreading, leveling, and finishing operations.

Typical gradings of the crushed stone used as cover material are given below:

	¾ to ½ inch	½ to ⅛ inch
Passing—	*Percent*	*Percent*
1¼-inch screen	100.0	
1-inch screen	98.2	
¾-inch screen	64.3	100.0
½-inch screen	7.5	93.4
No. 3 sieve	2.5	65.9
No. 10 sieve	1.5	8.3
No. 200 sieve		2.1

All of the surface treatments were applied in the summer of 1930 and their behavior up to the final inspection in October 1932 is described.

SURFACE TREATED SECTIONS DESCRIBED IN DETAIL

Section 14.—A heavy treatment of hot asphalt was applied.

The cut-back priming on the right half of the section had been down 5 days and the 50–60 slow-curing oil priming on the left side 3 days when the surface treatment was applied.

On this section an attempt was made to further smooth the surface by honing the seal coat cover. This procedure was abandoned, however, since it proved impossible to hone the surface without disturbing the larger underlying stone. It was therefore decided to use a broom drag on all cover courses and to limit the light honing operation to the heavy stone cover.

The application of the bituminous material on this section was unsatisfactory due to poor operation of the distributor. Many small areas were missed and considerable patching was necessary before applying the seal. The seal treatment was applied after the surface had been under traffic for about 3 weeks.

The cost of the base course was 31.98 cents per square yard, or $3,752 per mile. The cost of the surface treatment was 42.12 cents per square yard, or $4,942 per mile.

TABLE 7.—*Details of surface treatments applied to 3-inch compacted stone base, three-fourths inch to dust and bound with approximately one-fiftieth cubic yard per square yard of selected soil*

SECT	21		20		19		18		17		16		15		14	
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
	PRIME, 50-60 SLOW-CURING OIL 32 GAL ASPHALTIC EMULSION (STANDARD)¹		PRIME 50-60 SLOW-CURING OIL, 32 GAL ASPHALTIC EMULSION STANDARD	31 GAL	PRIME 50-60 SLOW CURING OIL 32 GAL ASPHALTIC EMULSION¹ 94+L2		PRIME, 50-60 SLOW-CURING OIL, 32 GAL ASPHALTIC EMULSION 90-95 L3	94+L2	PRIME 50-60 SLOW CURING OIL, .29 GAL 110-120 ASPHALT CUT BACK WITH NAPHTHA¹	PRIME, 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL	PRIME, 50-60 SLOW CURING OIL, .29 GAL 94+ ASPHALTIC [illegible]	PRIME 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL	[illegible] 94+ ASPHALTIC OIL, APPLIED HOT	PRIME [illegible] ASPHALT CUT BACK WITH KEROSENE, .29 GAL	PRIME 50-60 SLOW CURING OIL, .29 GAL [illegible] ASPHALTIC [illegible] APPLIED [illegible]	PRIME 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL
BITUMINOUS MATERIAL, GALLONS PER SQ YD	19 39 20	19 38 18	.26 35	25 37	16 28 25	26 29	15 27 35²	17 27 29	29 15 22	28 22 17	18 31 20	[illegible] 28 20	29	29	[illegible]	[illegible]
CRUSHED STONE FOR COVER: POUNDS PER SQ YD	45 8 26 11	44 7 24 11	44 11 21	44 10 25	47 8 17	48 30	47 16 6	58 3 13	50 19 11	37 15 13	32 18 13	32 34 12	27	27	[illegible]	[illegible]
CRUSHED STONE FOR COVER: SIZE IN INCHES	¾-½ ½-⅛ ½-⅛ ¼-⅛ (GRAVEL)	¾-½ ½-⅛ ½-⅛ ¼-⅛ (GRAVEL)	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	¾-½ ½-⅛ ½-⅛	½-⅛	½-⅛	[illegible]	[illegible]

94+66 121+06 147+80 174+20 200+60 227+07 251+47 279+87 [illegible]

¹ Quantities used in successive applications and corresponding applications of cover material are shown below.
² The final application consisted of 0.58 gallon of 90–95 L3 emulsion from stations 185+00 to 171+20 and 0.35 gallon of the 94+22 emulsion of the remainder of the section

	Left half	Right half
	(*a*) Base swept and holes repaired before priming	
Prime	0.29 gallon, 50–60 slow-curing oil of 17.6 specific viscosity (Engler) at 50° C.	0.29 gallon, 110–120 penetration asphalt cut back with kerosene to a specific viscosity (Engler) of 17.2 at 50° C.
	(*b*) Hand broomed and holes repaired as necessary	
Tack coat	0.26 gallon of 150–200 penetration asphalt applied hot.	0.26 gallon of 150–200 penetration asphalt applied hot.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	49 pounds, ¾- to ½-inch crushed stone.
	(*c*) Stone spread with spreader boxes, lightly honed with a blading machine, spotted, drag broomed and rolled	
Penetration application.	0.26 gallon of the same asphalt as that used in the tack coat application.	0.26 gallon of the same asphalt as that used in the tack coat application.
Keystone	31 pounds of ½- to ⅛-inch crushed stone.	31 pounds of ½- to ⅛-inch crushed stone.
	(*d*) Stone spread with spreader boxes, spotted, drag broomed and rolled	
Seal application	0.20 gallon of the same asphalt	0.20 gallon of the same asphalt
Cover	15 pounds, ½- to ⅛-inch crushed stone.	21 pounds, ½- to ⅛-inch crushed stone.
	(*e*) Drag broomed, spotted, and rolled	

The total cost was 74.10 cents per square yard, or $8,694 per mile.

Section 15.—A light surface treatment of a heavy asphaltic oil was applied hot.

	Left half	Right half
Prime	0.29 gallon, 50–60 slow-curing oil.	0.29 gallon, kerosene cut-back.
Hot application	0.29 gallon of 94+ asphaltic oil.	0.29 gallon of 94+ asphaltic oil.
Cover stone	27 pounds, ½- to ⅛-inch crushed stone.	27 pounds, ½- to ⅛-inch crushed stone.

Because of the light cover used in this treatment, smoothing by blading, as in the other sections, was not attempted. The equipment and methods used were otherwise the same.

The cost of the base was 32.1 cents per square yard, or $3,769 per mile. The cost of the surface treatment was 14.5 cents per square yard, or $1,707 per mile. The total cost was 46.68 cents per square yard, or $5,477 per mile.

Section 16.—A heavy surface treatment of a heavy asphaltic oil was applied hot.

The method of construction was similar to that used on the other heavy surface treatments. The subgrade conditions were about the same as on the other sections.

The cost of the base was 32.1 cents per square yard or $3,766 per mile. The cost of the surface treatment was 29.8 cents per square yard or $3,493 per mile. The total cost was 61.87 cents per square yard or $7,259 per mile.

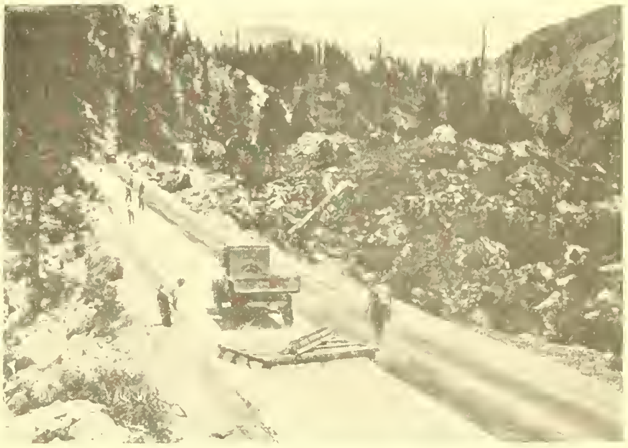

FIGURE 7.—TOUCHING UP SURFACE BY HAND AND DRAGGING WITH A BROOM.

	Left half	Right half
Prime	0.29 gallon, 50–60 slow-curing oil.	0.29 gallon, kerosene cut-back.
Tack coat	0.18 gallon of 94+ asphaltic oil.	0.11 gallon of 94+ asphaltic oil.
Cover stone	32 pounds of ¾- to ½-inch crushed stone.	32 pounds of ¾- to ½-inch crushed stone.
Penetration application.	0.31 gallon of 94+ asphaltic oil.	0.28 gallon of 94+ asphaltic oil.
Keystone	18 pounds, ½- to ⅛-inch crushed stone.	34 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.20 gallon of the same asphaltic oil.	0.20 gallon of the same asphaltic oil.
Seal cover	13 pounds, ½- to ⅛-inch crushed stone.	12 pounds, ½- to ⅛-inch crushed stone.

Section 17.—A heavy surface treatment of rapid-curing cut-back asphalt was applied.

	Left half	Right half
Prime	0.29 gallon of 50–60 slow-curing oil.	0.29 gallon of kerosene cut-back.
Tack coat application.	0.29 gallon of 110–120 asphalt cut back with about 25 percent naphtha.	0.28 gallon of 110–120 asphalt cut back with about 25 percent naphtha.
Cover stone	50 pounds, ¾- to ½-inch crushed stone	37 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.15 gallon of naphtha cut-back.	0.22 gallon of naphtha cut-back.
Keystone	19 pounds, ½- to ⅛-inch crushed stone.	15 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.22 gallon of naphtha cut-back.	0.17 gallon of naphtha cut-back
Seal cover	11 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.

The same methods were used in the construction of this section as on sections 14 and 16. The prime had been applied on the left side 18 days and on the right 20 days at the time the surface treatment was applied. The right half of the base which was primed with the cut-back asphalt was in perfect condition and free from holes or raveling, while the left side on which the 50–60 slow-curing oil was used had developed a few pot holes and some raveling.

The amount of cover stone used, particularly on the left half, was far too great for the quantity of asphalt used. An excessive amount of raveling occurred on this half before the seal coat was applied. The difficulty was corrected to some extent in applying the seal treatment by increasing the amount of asphalt and reducing the amount of stone cover.

The cost of the base was 32.6 cents per square yard or $3,825 per mile. The cost of the surface treatment was 38.7 cents per square yard or $4,544 per mile. The total cost was 71.33 cents per square yard or $8,369 per mile.

The high cost of this section was largely due to the cost of transporting the cut-back asphalt in steel drums, which was necessary because of the small quantity used.

Section 18.—A heavy surface treatment of asphalt emulsion was applied.

This section, as well as sections 19, 20, and 21, received surface treatments of essentially the same type as did sections 14, 16, and 17, except that asphaltic emulsions from two producers were used. The designs of the sections were furnished by the producers and the work was carried out under their supervision.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat application.	0.15 gallon of 90–95 L3 asphaltic emulsion.	0.17 gallon of 94+ L2 asphaltic emulsion.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	58 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.27 gallon of 90–95 L3 asphaltic emulsion.	0.27 gallon of 94+ L2 asphaltic emulsion.
Keystone	16 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.58 gallon of 90–95 L3 asphaltic emulsion from stations 185+00 to 174+20 and 0.35 gallon of the L2 grade on the remainder.	0.29 gallon of 94+ L2 asphaltic emulsion
Seal cover	16 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.

The prime coat had been down on the left side 8 days and on the right side 9 days before the surface treatment was applied. Holes and raveling which had developed during this time were repaired before applying the surface treatment.

The change in the grade of emulsion for the seal on the left side was made because of a shortage of L3 material. The emulsion was heated at the plant to about 140° F. in order to facilitate handling and spreading. The penetration application did not penetrate through the cover stone to meet the tack coat and, as a result, the stone was only partly coated. Failure from insufficient bituminous material was indicated by the large amount of raveling which occurred before the application of the seal treatment. Although the surface was considerably strengthened by the seal coat, failures by raveling continued to develop on many areas.

The cost of the base was 32.2 cents per square yard or $3,781 per mile. The cost of the surface treatment was 34.5 cents per square yard or $4,050 per mile. The total cost was 66.74 cents per square yard or $7,831 per mile.

Section 19.—A heavy surface treatment of asphaltic emulsion was applied.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat application.	0.16 gallon of 94+ L2 asphaltic emulsion.	0.26 gallon of 94+ L2 asphaltic emulsion.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	48 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.28 gallon of the same emulsion.	0.29 gallon of the same emulsion.
Keystone	8 pounds, ½- to ⅛-inch crushed stone.	30 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.25 gallon of the same emulsion.	None.
Seal cover	17 pounds, ½- to ⅛-inch crushed stone.	None.

The treatment on this section was essentially the same as that on section 18, except that the seal coat was applied only to the left half.

The priming coat had been down 8 days on the left half and 9 days on the right half when the surface treatment was applied. As on section 18, an insufficient amount of emulsion was used on this section. The cover stone was poorly coated, and the application did not penetrate through to the tack coat. Early loosening and raveling of the stone occurred under traffic.

The cost of the base was 32.7 cents per square yard or $3,834 per mile. The cost of the surface treatment was 26.9 cents per square yard or $3,160 per mile. The total cost was 59.61 cents per square yard or $6,994 per mile.

Section 20.—A heavy surface treatment of asphaltic emulsion was applied.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.31 gallon of 50–60 slow-curing oil.
Tack coat application.	0.26 gallon of asphaltic emulsion (standard).	0.25 gallon of asphaltic emulsion (standard).
Cover stone	44 pounds, ¾- to ½-inch crushed stone.	44 pounds, ¾-to ½-inch crushed stone.
Choke stone	11 pounds, ½- to ⅛-inch crushed stone.	10 pounds, ½- to ⅛-inch crushed stone.
Penetration application.	0.35 gallon of the same emulsion.	0.37 gallon of the same emulsion.
Keystone	21 pounds, ½- to ⅛-inch crushed stone.	25 pounds, ½- to ⅛-inch crushed stone.

The section differs from sections 18 and 19 in that a different asphaltic emulsion was used and also that a choke stone cover was added before the penetration application. No seal treatment was used.

It was apparent during the construction that the amount of emulsion used was insufficient to fully penetrate and coat the heavy stone cover. The use of a choke stone further increased the deficiency of asphalt. A similar deficiency had been apparent on sections 18 and 19 but additional stone cover was not used on those sections. Excessive raveling occurred in the surface shortly after construction and it was soon apparent that this section would not prove entirely satisfactory.

The cost of the base was 31.3 cents per square yard and $3,674 per mile. The cost of the surface treatment, including the cost of the emulsion, was 27.2 cents per square yard or $3,196 per mile. The total cost was 58.55 cents per square yard or $6,870 per mile.

Section 21.—A heavy surface treatment of asphaltic emulsion was applied.

The method of construction was similar to that on section 20, except that a seal treatment was applied. As was the case in all the experiments with emulsions the stone was poorly coated due to the use of an insufficient amount of bituminous material. The surface showed early indications of weakness and failure from this cause.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat	0.19 gallon of asphaltic emulsion (standard).	0.19 gallon of asphaltic emulsion (standard).
Cover stone	45 pounds, ¾- to ½-inch crushed stone.	44 pounds, ¾- to ½-inch crushed stone.
Choke stone	8 pounds, ½- to ⅛-inch crushed stone.	7 pounds, ½- to ⅛-inch crushed stone.
Penetration application.	0.39 gallon of the same emulsion.	0.38 gallon of the same emulsion.
Keystone	26 pounds, ½- to ⅛- inch crushed stone.	24 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.20 gallon of the same emulsion.	0.18 gallon of the same emulsion.
Seal cover	11 pounds, ¼- to ⅛-inch gravel.	11 pounds, ¼- to ⅛-inch gravel.

The cost of the base was 35.4 cents per square yard or $4,158 per mile. The cost of the surface treatment was 33 cents per square yard or $3,876 per mile. The total cost was 68.47 cents per square yard or $8,034 per mile.

PERFORMANCE OF SURFACE-TREATED SECTIONS NOT SATISFACTORY

The behavior of the surface-treated sections was, in general, unsatisfactory. In the spring following construction, extensive failures had occurred.

Except on section 21 which was discontinued as an experiment and rebuilt, these failures were repaired during the early summer. In the fall a light surface treatment was added to sections 18, 19, and 20. This treatment consisted of applying one-quarter gallon of emulsion, of the type and grade used on the original construction, covering with screenings at the rate of about 25 pounds per square yard and rolling.

Following this maintenance work in the fall of 1931 all the sections appeared in good condition. However, failures occurred again during the winter of 1931–32 to such an extent that it was decided to discontinue all the surface-treatment experiments.

Although other factors, particularly the subgrade conditions and the operation of heavy equipment for snow removal, seriously affected the behavior of the sections, an important cause of early failure was insufficient bituminous material.

As shown in table 8, all of the surface-treatment experiments except section 15 and the left half of section 16 were greatly deficient in bituminous material. Because of the low specific gravity of the cover stone, which weighed only 1,970 pounds per cubic yard, this deficiency was actually greater than the quantities used might indicate. Table 8 gives the percentages by weight of bitumen which would have resulted had the same volume of asphaltic material been used with the same weight of aggregate but weighing 2,700 pounds per cubic yard.

Experience has shown that surface-treated wearing surfaces require approximately 0.1 gallon of bitumen for each 10 pounds of cover, particularly where the subgrade is poor. It is believed that had these sections been built with quantities conforming more closely to this rule the surfaces would have been better bonded and more plastic and would therefore have been more satisfactory, particularly for the conditions which prevailed on this project.

Considering the character of the subgrade, the unfavorable drainage during the early spring months and the use of very heavy snow-removal equipment, it is evident that the conditions were unfavorable for any type of thin surface treatment, and were particularly so for the lean surface treatments used on this project.

CONSTRUCTION COST DETAILS GIVEN

Due to the experimental nature of the project and to the short sections built, the actual costs of the different surfaces are excessively high and would no doubt be considerably reduced in the construction of an appreciable mileage of any one type. Table 9 gives details of costs by sections and the following tabulation gives

TABLE 8.—*Quantity of bitumen and stone cover used on each of the surface treatments and conclusions as to the sufficiency of bitumen based on construction and early service behavior*

Section and lane	Bituminous material		Stone cover	Seal	Cover stone used for each 0.1 gallon of bitumen		Calculated bitumen		Adequacy of amount of bitumen used based on behavior of the surfaces
	Types	Gallons per square yard			Stone as used weighing 1,970 pounds per cubic yard	Based on equal volume of stone weighing 2,700 pounds per cubic yard	With the stone used weighing 1,970 pounds per cubic yard	Based on equal volume of stone weighing 2,700 pounds per cubic yard	
			Pounds per square yard		*Pounds*	*Pounds*	*Percentage by weight*	*Percentage by weight*	
14, Left	150-200 asphalt, hot	0.72	93	Applied	13	18	6.1	4.5	Deficient.
Right		.72	101	do	14	19	5.6	4.1	Do.
15, Left	94+ asphaltic oil, hot	.29	27	None	9	12	8.2	6.0	Satisfactory.
Right		.29	27	do	9	12	8.2	6.0	Do.
16, Left	do	.69	63	Applied	9	12	8.4	6.1	Do.
Right		.59	78	do	13	18	5.9	4.3	Slightly deficient.
17, Left	Asphalt cut back with naphtha [1]	.66	80	do	15	21	5.2	3.8	Deficient.
Right		.67	65	do	12	16	6.4	4.7	Slightly deficient.
18, Left [1]	Emulsion [3]	.77	79	do	19	26	4.4	3.2	Greatly deficient.
Left [2]		1.00	79	do	14	19	5.6	4.1	Deficient.
Right		.73	84	do	21	29	3.9	2.8	Greatly deficient.
19, Left	do [3]	.69	72	do	19	26	4.3	3.1	Do.
Right		.55	78	None	25	34	3.2	2.3	Do.
20, Left	do [3]	.61	76	do	22	30	3.6	2.6	Do.
Right		.62	79	do	23	32	3.5	2.5	Do.
21, Left	do [3]	.78	90	Applied	21	29	3.9	2.8	Do.
Right		.75	86	do	21	29	3.9	2.8	Do.

[1] In the calculation, emulsion was assumed to contain 56 percent of bitumen and the naphtha cut-back 80-percent residual bitumen.

[2] Stations 185 to 200+60.

[3] Stations 174+20 to 185.

TABLE 9.—*Cost of construction and maintenance of the experimental sections*

Sections	Date constructed	Cost of construction		Cost per square yard of maintaining bituminous surfaces										Annual cost per mile of maintenance
		Per square yard	Per mile	Total to October 1930	October 1930 to January 1931	January 1931 to April 1931	April 1931 to July 1931	July 1931 to October 1931	October 1931 to January 1932	January 1932 to April 1932	April 1932 to July 1932	July 1932 to October 1932	October 1932 to July 1933	
		Cents	*Dollars*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Dollars*
1, A	September 1929	46.94	5,507											
1, B	do	51.18	6,005					0.72	0.22	0.19	0.36	[1] 3.41	None	153
1, C	do	58.57	6,872											
2	do	66.50	7,802				0.07	.43	.22		.29	.61	None	51
3	do	69.68	8,175	0.28			.30	.15			.37	[1] 5.42	None	204
4	do	44.57	5,229	.31			.35	1.13	.31		.71	[1] 1.82	None	145
5	do	52.03	6,105				.44	.54			.32	[1] 2.45	None	117
6	do	47.17	5,534				.11	.11		.04	.57	.50	None	42
7	do	47.82	5,611				.22	.68				1.43	None	73
8	do	59.55	6,987	13.29	(2)									
9	do	50.81	5,962				.07		.28					11
10	do	71.19	8,353				.05	.14	.81		.21			38
11	do	64.46	[3] 7,563	1.51		0.06	7.82	.36			(4)	(4)	(4)	
12	do	64.62	[3] 7,582	1.33			.85	.03			(4)	(4)	(4)	
13	do	67.29	[3] 7,895	1.19			3.30	.20	.55		(4)	(4)	(4)	
14	July 1930	74.10	8,694			.32	1.00	.63	.22	(2)				
15	do	46.68	5,477			.11	1.19	.38	.31	(2)				
16	do	61.87	7,259		0.05	.67	1.13	.18	.11	(2)				
17	do	71.33	8,369			.08	.29	.05	.13	(2)				
18	do	66.74	7,831		.32	.45	1.92	[1] 9.75		(2)				
19	do	59.61	6,994	.10	.03	.22	6.00	[1] 9.90		(2)				
20	do	58.55	6,870	.03		.24	1.19	[1] 11.28		(2)				
21	do	68.47	8,034		1.10	1.45	2.01	(2)						

[1] Experiment retreated in part only; cost prorated over entire experimeut.
[2] Surface failed and experiment discontinued
[3] Includes seal applied in 1930 to complete construction.
[4] Maintenance cost not reported.

the average unit cost of some of the more important items entering into the construction of the experimental sections:

	Per cubic yard
Local stone at crushing plant:	
¾ inch to dust	$1.19
¾ to ⅛ inch	2.46
¾ to ½ inch	1.44
½ to ⅛ inch	.99
Other aggregates, f. o. b. destination:	
Crushed gravel, ¾ inch to dust, per cubic yard	$2.78
Fine sand filler (muck sand), per ton	2.25

Up to the time of the inspection in 1932 the eight surface-treated sections had required complete reconstruction. The three road-mix sections on which emulsions were used had received extensive repairs where subgrade failures had occurred. The road-mix section with 70–80 oil and open-graded aggregate had been reconstructed by extensive foundation repairs and by reworking the surface with the addition of fines. The remaining nine sections, all of the road-mix type, had required some repairs due primarily to base failures but were generally in good condition.

Later inspection of the experimental sections in 1934, 5 years after construction, showed that all of the road-mix sections were in serviceable condition. No extensive maintenance or reconstruction had been required except over certain areas where poor subgrade and drainage existed. A seal coat of hot oil had been applied to portions of sections 1, 3, 4, 5, and 7 and to all of sections 11, 12, and 13.

RESULTS OF INVESTIGATION SUMMARIZED

A summary of the more important results follows:

1. Portions of the oil-mix sections were affected by capillary moisture which resulted in the surface becoming soft and unstable.
2. The effect of moisture on the road-mix sections with slow-curing oils was greatest with the rich mixes and on areas where the drainage was not satisfactory, as well as on subgrades having high capillarity.
3. The road-mix surfaces containing emulsion and cut-back asphalt did not lose stability or develop soft areas from the action of moisture as did several of the oil-mix sections.
4. The action of moisture seemed to be more severe on the oil and gravel mixes than on the oil and crushed stone mixes.
5. The excellent behavior of a lean oil mix with a light surface treatment of heavy asphaltic oil and stone chips suggests possible advantages of this type over the richer and unsealed oil mixes, particularly where moisture conditions are unfavorable.
6. Satisfactory repair of those portions of the oil-mix surfaces which softened was obtained by scarifying and remixing.
7. Slow-curing or medium-curing bituminous materials should be used for road-mix construction with aggregates of the dense-graded type, while the more rapid-curing materials are best adapted to aggregates of the more open type (those containing less than 5 percent of material passing the no. 200 sieve).
8. The results of these experiments indicate that several of the formulas now in use are satisfactory for determining the amount of bituminous material required as binder in road-mix construction with the lighter slow-curing oils and close-graded aggregates.
9. For the very heavy slow-curing oils and the cutbacks and emulsions which develop heavy asphaltic residues in the road surface, somewhat greater quantities than those indicated by the formulas may be used to advantage.
10. Early failure of the road-mix sections occurred generally where unsatisfactory subgrade conditions existed. In the case of the unsealed portions of the road-mixes containing emulsions, failure was hastened by the open and porous condition of the mix.
11. Early failure of the treated surfaces was due to the unsatisfactory subgrade and the use of an insufficient amount of bituminous material which resulted in surfaces which were highly friable and poorly bonded. Because of the dust content and low specific gravity of the stone cover, the deficiency in bituminous material was greater than the quantities indicate when expressed by weight.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$3,947,753	$2,129,921	$4,617,753	$2,514,859	$35,890	252.8	$2,532,250	$1,231,350	$261,873	160.3	$129,086	$882,957	51.4	$72,458	$949,202
Arizona	3,878,555	1,338,712	4,348,078	3,713,426	41,269	290.8	790,917	157,724	618,953	47.6	4,655	205,880	20.6	2,750	472,610
Arkansas	3,334,167	1,714,000	2,444,464	1,886,556	138,919	134.0	1,464,499	1,293,409		43.9	72,616	779,146	36.4	81,587	795,935
California	7,912,928	3,713,643	7,224,499	5,391,792		241.8	5,007,793	2,514,683	881,600	87.0		690,800	23.9	6,453	2,141,243
Colorado	3,437,265	2,424,504	3,508,159	3,376,400	49,399	155.0	1,684,085	16,425	1,608,755	84.5	10,047	341,238	26.0	34,393	425,113
Connecticut	1,404,213	607,500	618,204	618,204		10.7	1,489,477	786,009	520,000	25.4		12,499			75,001
Delaware	892,544	461,697	876,080	873,987		33.4	465,318		450,140	10.7				18,557	11,557
Florida	2,519,011	1,330,672	2,808,803	2,068,798		103.3	778,633	372,460	273,046	27.4	6,136	477,283	18.8	71,617	580,343
Georgia	5,045,592	2,556,745	3,254,753	3,227,544		238.4	1,474,891	1,190,244	140,502	66.0	588,902	609,105	50.8	38,903	1,807,138
Idaho	2,166,858	1,131,910	2,068,561	1,985,815	14,243	177.9	605,246	171,151	421,900	32.8		101,297	14.7	9,892	594,470
Illinois	4,468,247	3,060,041	1,796,692	1,792,514		32.2	2,757,430	2,479,132	278,298	33.2	170,911	502,879	6.5	25,690	2,278,863
Indiana	5,018,921	2,843,478	3,033,316	3,025,496		100.7	1,705,868	1,705,128		38.5	288,297	601,151	76.6		2,242,327
Iowa	5,027,830	2,217,361	4,846,999	4,618,969		253.3	1,748,392	380,600	1,274,197	137.4		545,325	31.0	28,261	397,839
Kansas	5,044,802	2,558,837	5,211,591	4,888,918	84,944	453.7	1,260,995	75,293	1,185,701	197.7		1,279,231	102.6	80,590	8,962
Kentucky	3,751,605	1,527,324	3,440,744	3,264,209		238.3	734,208	359,844	268,733	46.0	109,476	210,452	33.9	18,076	1,048,139
Louisiana	2,711,152	1,380,419	1,524,551	1,520,772		61.5	1,872,012	1,139,887	225,474	23.9	45,845	823,944	11.8	4,648	331,001
Maine	1,617,560	793,644	1,309,462	1,284,365		43.1	815,140	241,620	563,051	13.7	28,442	197,402	7.3	63,134	33,191
Maryland	1,782,263	289,609	787,781	778,132		14.6	771,952	665,366	106,586	16.1	204,764	137,014	6.0	134,000	46,009
Massachusetts	1,101,716	1,632,874	1,159,396	870,145		32.5	701,966	157,399	389,045	14.1		257,343	1.1	74,172	986,485
Michigan	6,113,389	3,226,284	4,670,420	4,600,283		216.6	2,391,675	1,451,250	925,625	96.3		749,475	21.1	61,856	1,551,184
Minnesota	4,561,011	2,642,244	5,576,835	4,327,180	1,170,809	842.2	774,333	183,627	525,305	114.1		494,274	81.2	50,203	451,855
Mississippi	3,469,337	2,301,148	3,152,453	1,701,224		162.6	3,296,163	1,609,029	414,197	175.2	30,117	296,003	16.7	148,966	1,590,947
Missouri	5,237,532	2,778,183	4,630,609	4,096,746		187.4	2,354,158	756,989	1,343,156	69.1	293,639	169,716	5.5	90,158	1,265,311
Montana	4,463,849	2,714,208	5,168,105	4,417,657	109,308	386.4	1,720,383	36,653	1,614,773	193.2		154,417	16.7	9,539	835,711
Nebraska	3,914,481	1,982,182	4,538,382	3,449,750	27,348	324.9	1,843,153	464,731	941,321	99.1		936,113	52.3		77,400
Nevada	2,909,387	1,350,356	2,724,343	2,674,841		259.3	919,397	151,423	767,974	110.4	17,735	14,755	2.6	65,388	567,627
New Hampshire	725,739	484,731	642,877	623,374		10.8	425,572	79,730	324,780	11.2		118,599	1.3	22,635	41,352
New Jersey	3,173,019	951,379	1,713,050	1,693,518		31.9	1,435,567	1,296,101		15.3	97,912	105,868	2.7	85,489	845,510
New Mexico	2,846,648	1,676,769	2,922,244	2,760,948	17,366	277.6	1,113,756	18,762	1,094,994	106.4	66,938	116,186	10.2		448,223
New York	10,465,672	2,872,521	9,793,718	8,352,868	53,000	207.0	7,842,928	2,109,693	2,161,600	137.9		205,950	8.3	3,111	451,971
North Carolina	4,761,147	2,040,068	4,352,701	3,615,766	57,146	568.5	1,156,761	513,353	248,597	109.8	253,058	216,298	41.1	378,970	1,518,027
North Dakota	2,902,224	1,469,484	3,090,149	2,652,776	31,434	990.2	369,554	72,297	219,180	134.7	46,049	383,341	230.4	131,102	835,529
Ohio	7,277,758	3,539,256	7,370,525	7,037,866		188.4	1,003,710	70,898	647,290	19.8		1,812,206	38.0	168,994	1,079,759
Oklahoma	4,608,399	2,342,590	3,646,829	3,584,048		272.9	1,170,417	739,622	412,496	53.9	278,381	1,344,180	66.3	6,348	585,913
Oregon	3,053,448	1,452,741	3,329,545	2,996,112		182.8	1,126,918	24,519	1,027,499	47.9		80,857	8.0	32,817	344,386
Pennsylvania	6,691,194	4,554,082	5,042,718	4,868,286	17,389	117.6	4,033,104	1,732,286	2,103,471	62.8	17,361	2,049,106	39.8	73,261	384,116
Rhode Island	979,367	464,572	984,804	921,936		20.5	298,876	46,205	210,273	8.1		245,737	3.4	11,226	8,562
South Carolina	2,729,583	1,385,477	1,927,023	1,923,409		162.5	1,048,651	746,353	285,865	93.7	14,500	174,101	11.2	45,321	925,512
South Dakota	3,005,739	1,523,821	2,810,564	2,385,615		428.5	673,573	547,825	93,171	174.7	72,299	745,511	127.9		685,140
Tennessee	4,246,309	2,105,453	3,660,867	3,059,845		149.6	1,584,579	998,204	489,974	49.6	155,447	503,096	25.1	32,813	1,112,383
Texas	11,588,643	6,145,627	10,822,912	10,371,890		949.9	2,325,145	1,130,915	1,135,078	183.5	81,349	1,793,250	125.9	4,488	3,217,299
Utah	2,374,205	1,066,345	2,756,918	2,279,806	365,500	237.8	697,493	47,632	429,451	57.1	40,000	1,000	1.0	6,766	270,394
Vermont	928,184	466,042	975,782	913,366	29,890	47.9	277,219	10,670	249,114	13.9				4,148	187,038
Virginia	3,708,379	1,832,693	3,569,159	3,359,113		143.6	510,484	57,508	411,093	22.9	26,980	934,735	41.9	264,778	536,865
Washington	3,057,934	1,553,206	2,567,807	2,551,840		94.8	1,060,184	436,929	623,255	25.9	30,664	416,262	7.5	38,502	513,689
West Virginia	2,013,405	1,140,167	1,764,248	1,753,641		61.8	730,703	239,456	474,356	29.4		208,412	7.4	20,308	457,399
Wisconsin	4,697,518	1,865,947	4,458,518	4,342,445	549	213.1	661,175	239,442	322,490	35.9	50,000	724,898	31.2	65,632	818,010
Wyoming	2,250,663	1,692,907	2,320,263	2,038,160	67,583	469.8	1,093,538	195,228	872,144	131.8	16,766	531,702	100.4	509	221,478
District of Columbia															
Hawaii	1,683,956	598,778	254,428	178,070		10.9	1,766,159	1,437,846		28.1	66,000		.7	2,040	598,778
TOTALS	185,521,101	93,982,152	166,118,682	147,233,280	2,311,986	11,085.8	74,366,400	32,382,900	29,836,376	3,517.9	3,314,372	24,180,994	1,645.2	2,590,549	37,652,796

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,389,928	$1,064,961	$980,045	$980,045		25.8	$1,251,292	$1,234,924	$16,368	37.4	$21,289	$98,661	4.0	$153,670	$949,931
Arizona	807,982	305,191	626,513	618,491	$6,592	12.3	20,819	500	15,124	.7	149,322	2,709	.9	39,670	280,766
Arkansas	1,964,534	857,025	1,198,104	1,101,038		32.0	686,211	667,122		11.7	146,732	17,953	1.9	49,643	839,072
California	4,213,936	2,219,360	3,896,733	3,402,117		46.7	1,054,196	789,009	43,200	6.5		403,500	6.2	22,859	1,772,660
Colorado	1,718,633	190,000	1,755,371	1,705,334		35.2	19,122		19,122	1.8		170,878	2.0	13,299	
Connecticut	802,407	426,500	806,490	802,407		10.2	6,892		6,892			155,920	1.2		263,687
Delaware	477,680	230,849	474,326	466,045		7.4	54,180		54,180	.7	4,323		.7	7,313	176,669
Florida	1,410,008	665,336	911,221	670,710		10.4	796,390	725,501	70,889	10.2	7,721	24,263	.6	6,075	570,184
Georgia	2,724,620	1,278,373	1,118,295	1,117,289		49.5	747,558	747,558		18.7	596,332	67,440	8.2	263,440	1,210,933
Idaho	1,197,829	321,126	837,839	799,532	2,643	19.2	390,046	367,764	22,282	1.6		2,156	.2	30,533	294,045
Illinois	7,692,483	2,515,835	5,606,631	5,556,567		61.4	1,888,283	1,862,346	25,937	10.6	57,163	439,067	3.7	216,408	2,050,831
Indiana	4,287,050	2,035,585	2,614,514	2,604,092		58.1	1,458,175	1,458,026		13.2	166,973	159,463	5.4	57,959	1,876,122
Iowa	2,614,472	1,311,000	1,774,151	1,678,664	3,680	51.3	867,626	789,808	36,963	9.1	146,000	177,354	8.3		1,093,003
Kansas	2,522,401	1,279,419	2,030,425	2,010,283	1,285	36.8	891,244	453,792	292,599	7.1	32,129	985,535	10.0	26,198	
Kentucky	1,927,828	954,578	1,290,289	1,273,301		29.1	606,461	558,334	43,798	4.9	94,506	247,387	5.7	1,687	663,393
Louisiana	1,718,577	744,560	610,276	610,274		14.1	927,581	879,754	21,233	13.5	143,577	106,356	5.8	84,972	616,971
Maine	909,878	490,045	808,427	802,833		16.4	38,606	38,606		.4		111,539	.8	68,440	378,506
Maryland	891,132	452,515	388,284	384,134		4.1	911,650	98,129		.4				408,869	452,515
Massachusetts	5,007,199	847,600	1,315,478	1,273,933		10.7	3,692,649	3,615,424	52,248	6.8		141,429	.7	117,841	653,923
Michigan	3,438,781	1,613,142	2,362,064	2,346,755		35.9	2,207,865	1,085,565	1,109,800	11.2	6,461	211,400	7.1		291,942
Minnesota	3,719,143	1,421,494	3,243,704	3,019,572	193,497	106.7	362,446	155,856	198,390	9.7		40,724	6.4	543,715	988,883
Mississippi	1,744,669	885,056	554,462	542,002		19.5	728,456	665,432	63,024	24.0	281,960	54,974	7.1	255,275	767,059
Missouri	4,019,501	1,543,435	2,126,474	1,975,278		48.7	1,670,615	1,501,987	144,128	12.7	46,509	395,411	2.4	495,727	1,003,896
Montana	1,115,962	113,092	1,064,837	1,062,457		32.4	65,264	34,716	5,994	4.5	8,796	33,230	3.2	9,992	73,868
Nebraska	1,957,240	991,091	1,163,906	1,071,939	79,637	30.7	1,121,477	881,804	239,673	7.9		502,172	9.7	3,497	169,608
Nevada	500,051	100,000	501,943	483,944		8.8					16,107	50,332	1.5		49,668
New Hampshire	706,640	242,366	681,187	678,670		15.6	176,185		175,975	3.4				27,970	66,391
New Jersey	3,117,921	1,809,500	2,383,144	2,284,751		20.0	843,545	813,545		2.8		399,314	4.2	19,625	1,410,186
New Mexico	1,674,158	529,506	1,352,595	1,352,595		30.6	400,136	220,039	180,097	9.6		60,330	1.7	101,524	289,079
New York	8,255,661	4,203,000	5,511,788	5,164,770		51.7	4,473,856	3,057,756	1,246,200	24.3		1,282,300	7.1	33,135	1,674,500
North Carolina	2,380,573	1,210,236	1,842,389	1,813,467	26,797	72.6	412,006	337,602	30,837	9.2	127,497	37,135	3.5	102,007	1,115,467
North Dakota	1,451,112	734,742	1,007,990	1,005,717		42.4	217,558	142,308	75,250	8.3	277,222	55,501	14.2	25,864	603,991
Ohio	4,335,686	2,359,503	4,451,179	3,971,268		56.0	521,580	323,138	167,700	6.5		804,400	11.7	41,280	1,387,404
Oklahoma	2,304,200	1,171,295	1,752,643	1,731,058		38.3	527,828	506,493		8.1	65,270	389,880	5.3	1,379	781,415
Oregon	1,526,724	867,977	1,361,445	1,343,930		25.7	127,593	127,593		2.1	30,841	265,959	6.7	24,360	602,018
Pennsylvania	4,854,988	2,397,703	3,227,172	3,116,628	19,191	53.1	1,787,936	1,503,424	274,030	16.4	193,049	1,534,932	15.9	41,887	569,550
Rhode Island	579,625	255,000	527,914	527,015		7.4						40,627	.6	52,609	214,373
South Carolina	1,364,791	692,738	806,757	805,679		27.5	388,252	384,108	4,144	15.0	100,311		1.6	74,693	688,594
South Dakota	1,502,870	761,911	1,083,540	1,083,540		36.1	73,967	73,799	168	4.5	72,640	29,169	4.9	272,891	732,574
Tennessee	2,123,155	1,121,790	1,546,795	1,540,995		22.7	519,035	457,328	61,707	4.8	118,647	221,727	3.6	6,185	838,356
Texas	6,642,863	3,072,813	3,688,185	3,579,204		101.1	2,868,207	2,703,917		19.8	254,107	53,952	6.6	105,635	3,018,861
Utah	771,826	533,173	749,910	652,514	65,900	20.2	76,221		71,000	1.9	115,000	245,000	6.7	4,312	151,273
Vermont	500,509	240,611	465,187	441,585		12.9	78,014	58,924	18,000	1.8		48,000	1.1		174,611
Virginia	2,008,458	941,347	1,270,817	1,243,195		24.6	803,985	457,115	150,144	4.3	32,212	154,448	4.9	275,936	636,755
Washington	1,977,260	776,603	1,950,946	1,933,290		32.4	134,257		134,257	4.1	36,458	292,329	8.1	7,512	350,017
West Virginia	1,342,270	570,085	804,536	804,536		15.5	559,095	506,641	28,109	5.9				31,094	541,976
Wisconsin	2,596,143	1,293,455	2,534,030	2,473,556	15,575	52.4	327,925	116,488	211,437	6.3		128,516	2.8	6,099	937,927
Wyoming	1,125,332	22,877	1,031,616	1,028,227		22.3	104,315	97,105	6,629	2.6		6,249	.7		9,999
District of Columbia	968,235	243,460	861,028	704,305	156,723	5.9	322,521	250,164	72,357	.7				13,766	14,381
Hawaii															
TOTALS	115,884,974	50,908,859	80,953,595	77,639,531	571,520	1,600.4	38,209,121	30,749,444	5,389,885	387.7	3,349,154	10,649,621	215.6	4,146,845	34,297,833

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2.032.452	$ 1,064.960	$ 328.712	$ 328.712		16.0	$ 1,602.627	$ 1.545.599	$ 57.028	122.7	$ 123.547	$ 344.795	32.8	$ 34.594	$ 663.138
Arizona	525.423	998.032	530.237	517.610		42.3	155.442		139.878	14.5	7.813	112.459	3.9		745.695
Arkansas	1.449.634	857.024	765.223	764.238		123.4	562.188	557.188		37.2	59.132	127.302	27.3	69.076	729.722
California	3.480.440	1.999.203	2.851.174	2.370.743		130.6	1.430.072	1.109.697	126.600	53.8		456.556	14.3		1.416.047
Colorado	1.718.632	871.502	1.717.340	1.608.632	$ 11.000	174.2	864.466	110.000	341.287	158.2		112.695	5.7		406.519
Connecticut	659.120	420.868					887.796	659.120	222.880	19.0					197.988
Delaware	448.864	230,849	210.549	202.680	7.869	11.3	486.455	246.184	183.315	48.4					39.665
Florida	1.302.815	665.335	1.279.636	1.273.590		74.8	258.654		258.654	11.1		134.294	11.2	29.226	272.387
Georgia	2.320.973	1.278.373	1.056.732	1.055.479		80.9	973.308	973.308		65.1	183.491	139.830	15.3	108.695	1.138.543
Idaho	1.121.562	824.450	1.287.068	1.121.498	60.449	156.5	402.152		391.674	42.5		51.700	6.8	64	320.627
Illinois	5.410.040	3.345.525	1.761.827	1.757.460		118.9	4.253.782	3.563.263	690.519	243.1	89.317	1.811.109	85.6		843.898
Indiana	731.872	209.900	345.107	345.107		35.8	270.290	270.290		41.1	116.475	16.356	11.5		193.544
Iowa	2.413.358	1.590.000	1.883.103	1.812.595	15.800	257.6	1.146.993	516.950	473.150	210.7	38.200	690.300	152.5	45.613	410.750
Kansas	2,522.401	1.279.419	1.905.415	1.876.925	24.566	166.4	1.137.785	637.717	500.068	100.3	7.758	754.785	48.8		
Kentucky	1.837.926	1.336.409	1.765.773	1.729.492		205.9	555.671	85.833	453.118	56.8	21.369	214.471	32.0	1.232	668.820
Louisiana	1.398.862	838.953	950.765	949.942		45.1	326.143	323.941		14.3		155.403	9.0	124.978	683.550
Maine	842.479	427.897	1.042.171	828.393	137.550	90.4	283.371	5.000	258.312	23.1		16.994	.7	9.085	15.041
Maryland	891.132	1.067.934	622.914	613.642		47.5	479.375	252.997	212.451	27.1	20.419	291.894	11.0	4.074	563.589
Massachusetts	488.185	870.000	469.741	469.741		15.2								18.444	870.000
Michigan	3.184.057	1.613.142	2.830.230	2.813.830	16.400	201.7	976.027	370.227	590.900	40.1		359.700	17.4		646.142
Minnesota	2.376.415	1.361.813	2.282.932	2.204.016	58.916	233.1	764.074	155.444	450.830	98.5		237.567	33.7	16.956	614.500
Mississippi	1.744.669	354.023	444.928	444.928		55.6	1.016.355	1.016.355		92.3	216.589		15.7	66.797	354.023
Missouri	2.923.273	1.852.122	2.841.364	2.690.423	79.917	554.5	565.393	78.632	486.761	174.1	29.933	683.992	113.9	124.286	601.452
Montana	1.859.937	942.434	1.830.540	1.829.829		226.1	173.754		173.754	8.3		149.021	19.6	30.108	619.659
Nebraska	1.957.240	991.091	1.519.246	1.398.089	118.655	300.4	896.838	557.763	338.825	103.1		437.935	85.1	1.389	95.676
Nevada	1.136.479	852.000	1.133.078	1.037.806	75.272	133.3	251.481	98.673	128.402	22.3		169.404	20.0		478.921
New Hampshire	477.460	242.365	521.129	476.963		25.6	84.746		82.590	4.8		70.658	3.4	497	89.117
New Jersey	55.099	460.000	56.528	55.099		.5									460.000
New Mexico	1.272.129	735.425	1.226.434	1.226.434		207.4	122.479	35.000	87.479	30.9	10.695	427.908	37.1		220.038
New York	3.608.768	4.252.400	3.292.248	2.961.095	10.500	83.6	3.647.420	625.700	2.207.500	156.4		1.295.040	119.1	21.973	739.360
North Carolina	2.380.573	1.590.637	1.913.496	1.912.718		201.4	780.702	394.215	386.487	80.8		417.653	40.2	73.639	786.497
North Dakota	1.451.112	734.741	897.063	897.063		283.1	270.426	270.426		70.3	180.638	109.053	97.3	102.985	625.689
Ohio	3.871.148	1.966.253	4.064.393	3.768.518		297.8	418.610	73.810	344.800	73.8		317.600	30.3	28.820	1.303.853
Oklahoma	2.304.199	1.171.295	1.335.611	1.307.347		191.1	1.026.630	967.443		84.5	28.270	729.076	31.3	1.139	442.220
Oregon	1.526.724	777.096	1.710.635	1.496.761	23.904	112.0	426.789	19.526	364.143	32.3		116.801	18.0	10.437	272.248
Pennsylvania	7.344.822	2.639.003	5.864.869	5.726.999		493.3	2.893.406	1.613.823	1.274.488	244.9	4.000	1.122.863	27.7		241.652
Rhode Island	439.716	295.000	413.706	408.636		33.2						49.894	1.0	31.080	245.106
South Carolina	1.364.791	692.739	964.879	964.879		104.4	438.892	331.442	107.450	53.7		410.827	61.7	68.470	174.462
South Dakota	1.502.870	761.911	1.091.582	1.091.570		312.1	408.669	360.518	48.151	115.1	34.544		28.3	16.238	713.760
Tennessee	2.123.155	1.075.748	1.217.051	1.195.481		102.4	1.092.889	851.020	241.869	60.3	4.503	179.693	10.8	72.151	654.186
Texas	6.012.518	3.072.813	5.878.781	5.452.453		750.6	755.092	500.417	252.955	32.3	18.556	872.798	57.6	41.093	1.947.060
Utah	1.048.677	533.173	1.176.414	955.732	105.800	185.6	253.259	92.945	117.000	40.5		95.613	19.3		214.760
Vermont	438.880	241.354	405.920	386.990	7.391	33.1	170.794	50.328	108.023	11.2		80.990	6.5	1.563	44.950
Virginia	1.699.920	941.347	1.458.922	1.400.781		202.2	321.468	236.139	74.146	16.7	11.450	192.172	8.4	51.550	675.029
Washington	1.080.673	776.603	992.047	974.789		62.6	227.029	103.666	123.363	11.5		441.725	34.7	2.218	211.515
West Virginia	1.118.559	570.083	535.468	528.390		28.2	532.021	506.887		28.9	48.468	49.971	.1	34.813	520.112
Wisconsin	2.431.220	1.782.435	2.325.089	2.160.766	48.583	170.4	449.760	183.711	189.867	14.5	50.000	248.142	13.0	36.743	1.295.842
Wyoming	1.125.332	571.928	1.076.107	1.057.813		148.4	90.037		90.035	12.2	30.935	224.994	37.5	36.584	256.839
District of Columbia	950.234	730.382	1.046.829	931.582	115.247	8.5	99.768		99.768	1.8		312.510	1.8	18.651	202.856
Hawaii	187.106	351.000	177.718	177.718		4.9								9.388	351.000
TOTALS	92.593.925	55.108.989	73.298.724	69.561.977	917.819	7539.9	35.231.378	20.351.197	12.678.520	3.005.1	1.336.102	15.234.543	1.458.9	1.344.649	26.278.107

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$8,370,133	$4,259,842	$5,926,510	$3,823,616	$35,889	294.6	$5,386,169	$4,011,873	$335,269	320.4	$273,922	$1,326,413	88.2	$260,722	$2,562,271
Arizona	5,211,960	2,641,935	5,504,828	4,849,526	47,862	345.3	967,177	158,224	773,954	62.8	161,790	321,048	25.3	42,420	1,499,071
Arkansas	6,748,335	3,428,049	4,407,791	3,751,831	138,919	289.4	2,712,897	2,517,719		92.8	278,479	924,401	65.6	200,306	2,364,729
California	15,607,354	7,932,206	13,972,406	11,164,653		419.1	7,492,061	4,413,389	1,051,400	147.3		1,550,856	44.3	29,312	5,329,950
Colorado	6,874,530	3,486,006	6,980,869	6,690,366	60,399	364.4	2,567,674	126,425	1,969,164	244.4	10,047	624,811	33.7	47,692	831,632
Connecticut	2,865,740	1,454,868	1,424,694	1,420,611		21.0	2,384,165	1,445,129	749,772	44.5		168,420	1.2		536,676
Delaware	1,819,088	923,395	1,560,955	1,542,711	7,869	52.1	1,005,953	246,184	687,635	59.7	4,322		.7	25,870	227,891
Florida	5,231,834	2,661,343	4,999,661	4,013,099		188.5	1,833,676	1,097,960	602,589	48.7	13,858	635,840	30.6	106,918	1,422,914
Georgia	10,091,185	5,113,491	5,429,780	5,400,312		368.7	3,195,757	2,911,110	140,502	149.9	1,368,725	816,375	74.4	411,038	4,156,614
Idaho	4,486,249	2,277,486	4,193,469	3,906,845	77,335	353.7	1,397,445	538,915	835,856	76.9		155,153	21.7	40,489	1,209,142
Illinois	17,570,770	8,921,401	9,165,150	9,106,541		212.6	8,899,495	7,904,741	994,754	287.0	317,391	2,753,055	95.8	242,098	5,173,592
Indiana	10,037,843	5,088,963	5,992,936	5,974,695		194.6	3,434,334	3,433,444		92.8	571,744	776,970	93.6	57,959	4,311,993
Iowa	10,055,660	5,118,361	8,504,252	8,110,228	19,480	562.1	3,763,011	1,687,358	1,784,310	357.1	184,200	1,412,979	191.9	73,874	1,901,592
Kansas	10,089,604	5,117,675	9,147,431	8,776,126	110,795	656.8	3,290,024	1,166,802	1,978,367	305.2	39,887	3,019,551	161.3	106,788	8,962
Kentucky	7,517,359	3,818,311	6,496,806	6,267,001		473.4	1,896,340	1,004,011	765,649	107.8	225,352	672,310	71.7	20,995	2,380,352
Louisiana	5,828,591	2,963,932	3,085,591	3,080,988		120.8	3,125,736	2,343,583	246,707	51.6	189,422	1,085,703	26.6	214,598	1,631,522
Maine	3,369,917	1,711,586	3,160,060	2,915,591	137,550	149.9	1,137,116	285,225	821,363	37.2	28,442	325,935	8.8	140,659	426,738
Maryland	3,564,527	1,810,058	1,798,979	1,775,909		66.3	2,162,977	1,016,492	319,038	43.6	225,183	428,907	17.0	546,943	1,062,113
Massachusetts	6,597,100	3,350,474	2,944,616	2,613,820		58.5	4,394,615	3,772,823	441,294	20.9		398,772	1.7	210,457	2,510,408
Michigan	12,736,227	6,452,568	9,862,714	9,760,868	16,400	454.1	5,575,567	2,907,042	2,626,325	147.6	6,461	1,320,575	45.6	61,856	2,489,268
Minnesota	10,656,569	5,425,551	11,103,471	9,550,768	1,423,222	1,182.1	1,900,853	494,927	1,174,526	222.3		772,565	121.3	610,874	2,055,238
Mississippi	6,978,675	3,540,227	4,151,843	2,688,155		237.8	5,040,974	3,290,816	477,221	291.5	528,666	350,977	39.5	471,038	2,712,029
Missouri	12,180,306	6,173,740	9,598,447	8,762,446	79,917	790.6	4,590,166	2,337,608	1,974,045	255.9	370,081	1,249,120	121.8	710,171	2,870,659
Montana	7,439,748	3,769,734	8,063,482	7,309,943	109,308	644.8	1,959,401	71,369	1,794,521	205.9	8,796	336,667	39.6	49,639	1,529,238
Nebraska	7,828,961	3,964,364	7,221,535	5,919,778	225,640	656.0	3,861,468	1,904,298	1,519,820	210.1		1,876,220	147.1	4,886	342,684
Nevada	4,545,917	2,302,356	4,359,364	4,196,591	75,272	401.4	1,170,879	250,097	896,376	132.7	33,841	234,491	24.1	65,388	1,096,216
New Hampshire	1,909,839	969,462	1,845,193	1,779,007		52.1	686,503	79,730	583,345	19.3		189,257	4.7	51,102	196,860
New Jersey	6,346,039	3,220,879	4,152,723	4,033,367		52.4	2,279,112	2,109,646		18.1	97,912	505,182	6.9	105,114	2,715,696
New Mexico	5,792,935	2,941,700	5,501,272	5,339,977	17,366	515.6	1,636,371	273,801	1,362,570	146.9	77,633	604,424	49.0	101,524	957,340
New York	22,330,101	11,327,921	18,597,753	16,478,733	63,500	342.2	15,964,204	5,793,149	5,615,300	318.6		2,783,290	134.5	58,219	2,865,831
North Carolina	9,522,293	4,840,941	8,108,586	7,341,952	83,944	842.5	2,349,470	1,245,171	665,920	199.8	380,555	671,086	84.9	554,616	3,419,991
North Dakota	5,804,448	2,938,967	4,995,202	4,555,557	31,433	1,315.7	857,538	485,031	294,430	213.3	503,909	547,895	341.8	259,951	2,065,209
Ohio	15,484,592	7,865,012	15,886,098	14,777,651		542.2	1,943,900	467,846	1,159,790	100.1		2,934,206	80.0	239,094	3,771,016
Oklahoma	9,216,798	4,685,180	6,735,083	6,622,453		502.2	2,724,875	2,213,557	412,496	146.5	371,921	2,463,136	102.9	8,866	1,809,548
Oregon	6,106,896	3,097,814	6,401,625	5,836,803	23,904	320.5	1,681,299	171,638	1,391,641	82.3	30,841	463,617	32.6	67,614	1,218,652
Pennsylvania	18,891,004	9,590,788	14,134,759	13,711,913	36,580	664.1	8,714,446	4,849,533	3,651,989	324.1	214,410	4,706,901	83.4	115,148	1,195,318
Rhode Island	1,998,708	1,014,572	1,926,423	1,857,588		61.1	298,876	46,205	210,273	8.1		336,258	5.1	94,915	468,041
South Carolina	5,459,165	2,770,954	3,698,659	3,693,967		294.4	1,875,795	1,461,902	397,458	162.4	114,811	584,928	74.4	188,484	1,788,568
South Dakota	6,011,479	3,047,643	4,985,687	4,560,724		776.7	1,156,208	982,142	141,490	294.2	179,484	774,680	161.1	289,129	2,131,474
Tennessee	8,492,619	4,302,991	6,424,713	5,796,321		274.7	3,196,503	2,306,551	793,550	114.7	278,597	904,516	39.5	111,149	2,604,925
Texas	24,244,024	12,291,253	20,389,878	19,403,547		1,801.5	5,948,444	4,335,249	1,388,033	235.6	354,012	2,720,000	190.1	151,216	8,183,220
Utah	4,194,708	2,132,691	4,683,242	3,888,052	537,200	443.5	1,026,973	140,578	617,451	99.5	155,000	341,613	27.0	11,078	636,427
Vermont	1,867,573	948,007	1,846,889	1,741,940	37,281	93.9	526,027	119,922	375,137	26.9		128,990	7.6	5,711	406,599
Virginia	7,416,757	3,765,387	6,298,898	6,003,089		370.4	1,635,937	750,762	635,383	43.9	70,643	1,281,355	55.2	592,264	1,848,649
Washington	6,115,867	3,106,412	5,510,800	5,459,919		189.8	1,421,470	540,595	880,875	41.6	67,122	1,150,316	50.3	48,232	1,075,221
West Virginia	4,474,234	2,280,335	3,104,251	3,086,567		105.5	1,821,820	1,252,984	502,465	64.1	48,468	258,383	7.5	86,215	1,519,487
Wisconsin	9,724,881	4,941,837	9,317,637	8,976,767	64,707	435.8	1,438,860	539,641	723,795	56.7	100,000	1,101,556	47.0	108,474	3,051,779
Wyoming	4,501,327	2,287,712	4,427,986	4,124,200	67,583	640.5	1,287,890	292,334	968,808	146.7	47,701	762,945	138.6	37,093	488,376
District of Columbia	1,918,469	973,842	1,907,858	1,635,888	271,970	14.5	422,289	250,164	172,125	2.6		312,510	1.8	32,417	217,237
Hawaii	1,871,062	949,778	432,146	355,788		15.7	1,766,159	1,437,846		28.1	66,000		.7	11,428	949,778
TOTALS	394,000,000	200,000,000	320,371,001	294,434,788	3,801,325	20,226.1	147,806,899	83,483,541	47,904,781	6,910.7	7,999,628	50,065,158	3,319.7	8,082,043	98,228,736

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 12 FEBRUARY 1935

A SOIL ROAD IN ONONDAGA COUNTY, NEW YORK

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 15, No. 12 February 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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SOIL ROAD SURFACES

BY THE DIVISION OF TESTS, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by **C. A. HOGENTOGLER**, Senior Highway Engineer

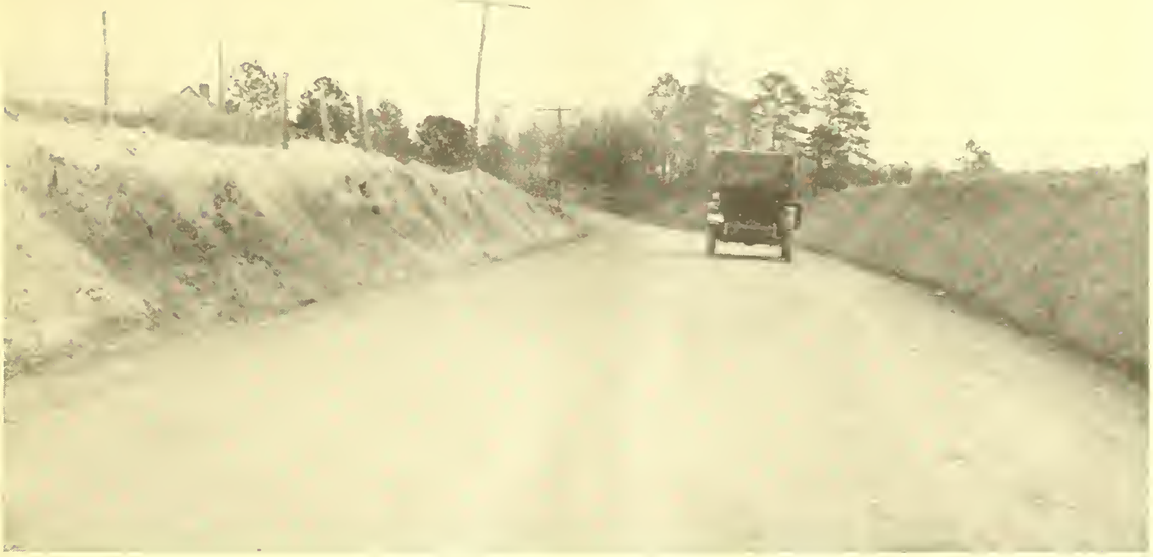

FIGURE 1.—A SAND-CLAY SURFACE IN MUSCOGEE COUNTY, GA.

SOIL is the oldest and probably the most used of all engineering materials. However, substantial contributions to our present knowledge of soils date only from the very recent time when the importance of the physical character of the soil and the effect of surface tension of contained moisture were first recognized.

The first studies in soil physics were inaugurated for the purpose of identifying properties important in agriculture and geology. Tests of physical properties developed in these studies were used in identifying topsoils suitable for use in road surfaces. Later these tests were used in classifying subgrades with respect to performance in supporting road surfaces. More recently they became the basis of research in soil mechanics and now they are being used in establishing the fundamental principles and construction procedures in the new field of soil stabilization.

PERFORMANCE OF SOILS DEPENDS UPON THE CHARACTER AND GRADING OF THE CONSTITUENTS

Milton Whitney in 1892, then chief of the Weather Bureau, first explained in detail the effect of surface tension in contracting, expanding, and supplying cohesion in soils.[1] He thus furnished the basis for the present method of soil identification by means of physical characteristics.

In 1898 Dr. George E. Ladd advanced two additional basic guides: That silt consists of bulky grains and clay of scalelike particles, and that shrinkage of soil is caused by surface tension when water recedes in the soil capillaries.[2]

Simple tests used in the present routine testing procedure to disclose the physical properties of road soils were devised by A. Atterberg, a Swedish scientist, as early as 1911.[3] However, it remained for A. C. Rose, of the United States Bureau of Public Roads, in 1924, to first correlate road surface performance with the results of tests devised to disclose the physical properties of subgrade soils.[4]

The publication of a treatise on soil mechanics by Charles Terzaghi in 1925[5] marks another important step in the progress of soil studies. For the first time mathematical formulas were available for determining quantitatively the effects of surface tension on the performance of soils.

Appropriate tests based upon Terzaghi's theory of consolidation opened the way to determining properties such as compressibility, expansibility, and permeability. With such information, furnished by tests on small samples in the laboratory, it became possible to estimate the ultimate settlements to be expected in foundations constructed on soft undersoils and also the rate at which they would be likely to occur.

Investigations begun in 1906 by Dr. C. M. Strahan,[6] then county engineer of Clark County, Ga., mark the first consistent effort to correlate the performance of topsoils in road surfaces with their gradings as determined by mechanical analyses.

The name "topsoil" was applied to soil skimmed from the surface of fields to shallow depths. It was thought that during long cultivation such deposits had undergone weathering, water separation, and the probable influence of organic acids which gave them their superior consistency and binding stability.

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[1] Weather Bulletin No. 4, U. S. Department of Agriculture.

[2] Geological Phenomena Resulting from the Surface Tension of Water, by George E. Ladd, American Geologist, vol. 22, no. 5, November 1898. Clays of Georgia, by George E. Ladd, Geological Survey of Georgia, Bull. No. 6–A, 1898.

[3] Über die physikalische Bodenuntersuchung, und Über die Plastizität der Tone, by A. Atterberg, Internationale Mitteilungen für Bodenkunde, vol. 1, 1911; see also Adaptation of Atterberg Plasticity Tests for Subgrade Soils, by A. M. Wintermyer, Public Roads, vol. 7, no. 6, August 1926.

[4] Practical Field Tests for Subgrade Soils, Public Roads, vol. 5, no. 6, August 1924; and Present Status of Subgrade Studies, Public Roads, vol. 6, no. 7, September 1925.

[5] Erdbaumechanik, by Charles Terzaghi, Vienna, 1925.

[6] Research Work on Semi-Gravel, Topsoil, and Sand-Clay, and Other Road Materials in Georgia, by Dr. C. M. Strahan, Bulletin of the University of Georgia, vol. 22, no. 5a, June 1932.

In Dr. Strahan's work samples were obtained from short stretches of existing roads where firmness and water-resisting qualities were noted in contrast with ordinary conditions of dirt roads. Fifty or more counties were visited during the study. The data from laboratory tests on the samples collected were related to the road behavior under varying weather conditions and traffic, and the conclusions reached became the basis for selecting materials and the adoption of laboratory standards.

The first statement of the probable mode of action of road soils under traffic and weather was prepared by Dr. Strahan in 1914 for distribution at the Fourth American Road Congress held that year in Atlanta, Ga.

After the passage of the Federal-aid act in 1916, the first conference of State highway testing engineers and chemists was called to meet in Washington, February 1917, under the auspices of the Bureau of Public Roads, to consult concerning standards and specifications for the various road building materials. A committee [7] on semigravel, topsoil, and sand-clay aggregates recommended gradings for three classes of topsoils, hard or class A, medium or class B, and soft or class C, and the recommendations were adopted.

The gradings adopted remained unchanged in subsequent reports by Dr. Strahan, the last of which was published in Public Roads, September 1929.

ROAD-SOIL GROUPINGS AND THEORY OF STABILITY DEVELOPED

A report [8] resulting from a combined attack on the road-soil problem by the soil physicist, the pedologist, and the geologist, cooperating with the highway engineer, published in 1929, added two new developments on the subject of soil studies which by this time was rapidly growing into proportions having all the semblance of a new branch of science. They were:

1. A procedure for testing soils in the laboratory and classifying them in groups according to a fixed classification schedule. All the soils in a given group have similar characteristics with regard to drainage and are similar in their effect on road design.
2. A mathematical theory of stability which gave some conception of the relative influence of such factors as the granular fraction, the cohesive fraction, the moisture content of the soil and the weight and the load distribution properties of the road surface.

The soil grouping proposed had the unique feature of indicating performance under existing conditions of traffic, construction, and climate. In this it differed from the older classifications of the geologist based upon geological origin and that of the agronomist based upon the pedologic development.

The development of this grouping was in response to the general question "What conspicuous performances of soil are of interest in the design, construction, and maintenance of highways?" Answers to this question form the basis of the group designations. Thus one group includes soils of high stability generally as distinguished from soils of other groups which may have high stability only under unusually moist conditions on one hand or unusually dry conditions on the other.

The groupings provide for separate classification of soils which are apt to heave detrimentally due to frost and the granular soils in which such trouble is not to be expected, and also the elastic soils in which special methods of preparation are required to eliminate detrimental rebound after consolidation and the compressible soils not characterized by such rebound.

In yet other groups are the soils which require special treatment in order that detrimental shrinkage or swell of the subgrade be prevented, and also the peaty and muck soils which give low support.

Within the groups of soils subject to frost heave there is the further distinction between those soils for which the corrective measure is drainage, those on which bituminous surface treatments or other impervious coverings prove beneficial and those which, because of high capillary properties, can be improved only by means of thick coverings of granular material.

The ultimate aim of this classification is to have each group designation signify characteristic performance of soils, the methods of improving performance, and the corresponding road surface requirements.

In this connection the gradings suggested by Dr. Strahan, modified in the light of new experience and supplemented by the results of simple physical tests, were adopted for use in the identification of the quality of soil mixtures and to disclose the effect of admixtures in improving the quality of the poorer soils.[9]

THE THEORY OF STABILITY DISCUSSED

Soil movement during loss of stability or rutting is illustrated by figure 2. It is assumed that the load is applied for an indefinite length over a width of 2*b*. For deformation under the load to occur, the section A must shear along some plane such as *S* and displace laterally as indicated in figure 2, B. But for this to occur, the adjacent section marked C must shear along some surface as *S′* and, in consequence, displace upward forming a bulge adjacent to the loaded area as shown in figure 2, C.

Actually the surfaces *S* and *S′* may be parts of a continuously curved surface but, for mathematical treatment, they may be considered as separate plane surfaces without introducing a large error.

If rutting is to be prevented, the prism *C* must resist displacement sufficiently to prevent the lateral bulging of the prism *A*. This may be accomplished by two means, separately or in combination. The shear strength along the planes *S* and *S′* must be sufficiently high to prevent sliding of the prisms, or sufficient weight must be placed adjacent to the loaded area to prevent the upward bulging of the prism *C*.

Friction between the granular particles, combined with the stickiness or cohesion furnished by clay or water films in the binder, control the shear strength of the soil. The road surface furnishes the weight adjacent to the loaded area.

Table 1 gives theoretical supporting values for conditions of load as shown in figure 2, and serves to illustrate the effect of internal friction and cohesion under varying moisture conditions. These data disclose that the supporting value of clay soils may drop from as much as about 12,000 pounds per square foot to less than 400 pounds per square foot with change

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[7] The committee consisted of C. M. Strahan, of Georgia; C. B. Scott, of Virginia; and I. B. Mullis, of North Carolina.

[8] Interrelationship of Load, Road and Subgrade, by C. A. Hogentogler and Charles Terzaghi, Public Roads, vol. 10, no. 3, May 1929.

[9] See Interrelationship of Load, Road, and Subgrade, by C. A. Hogentogler and Charles Terzaghi, Public Roads, vol. 10, no. 3, May 1929, p. 10; The Subgrade Soil Constants, Their Significance, and Their Application in Practice, Part 2, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Willis, Public Roads, vol. 12, no. 5, July 1931, p. 134; Tar Surface Treatment of Low Cost Roads, Public Roads, vol. 14, no. 1, March 1933, p. 13.

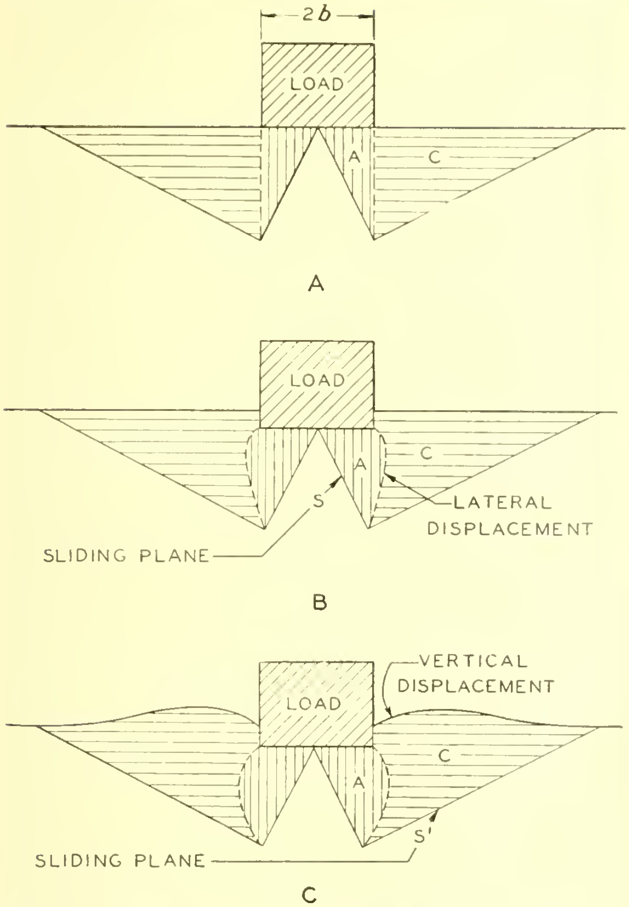

FIGURE 2.—SHEAR PLANES ALONG WHICH LATERAL DISPLACEMENT OF SOILS OCCURS.

from the dry or damp to a soft or almost liquid state. Since the computations are based on the assumption that the load is applied to a narrow strip of indefinite length, the conditions are different from those of a wheel load. The values given serve to illustrate the effect of moisture on stability and are not suggested as a basis for road design.

While the stability of a cohesionless sand may be less than 300 pounds per square foot and that of a fairly stiff clay about 5,000 pounds per square foot, these two materials properly combined may have a supporting value of more than 17,000 pounds per square foot. As a matter of fact, only the cohesion of an almost liquid clay, about 130 pounds per square foot, is required to increase the supporting value of cohesionless sand from 270 pounds per square foot to 2,500 pounds per square foot.

The essential consideration in stabilization is to provide the combination of internal friction and cohesion required to furnish the soil with high shearing strength. This quality is necessary in road surfaces, subgrades, and bases for thin wearing courses. Regardless of the methods used to provide high shearing strength, the success of the efforts will depend upon the permanent adhesive strength which can be developed by the minute films, whether of water or of special chemical substances which connect the soil particles.

TABLE 1.—*Influence of internal friction and cohesion upon the stability of soils*

Soil type	Cohesion c	Angle of internal friction ϕ	Supporting value, q[1]	Cohesion c required to increase q to 2,500 pounds per square foot
	Lbs. per sq. ft.	*Degrees*	*Lbs. per sq. ft.*	*Lbs. per sq. ft.*
Clay, liquid	100	0	400	------
Clay, very soft	200	2	860	------
Clay, soft	400	4	1,850	------
Clay, fairly stiff	1,000	6	4,970	------
Clay, very stiff	2,000	12	12,490	------
Sand, dry	0	34	270	131
Cemented sand and gravel	1,000	34	17,340	------

[1] Computations based on assumptions that weight of the soil equals 100 pounds per cubic foot and width of loaded area equals 3 inches.

It is well known that the denser the soil, the greater is its stability. This is due only in part to the greater mechanical bond resulting from the closer association of grains. Of more importance is the fact that the thinner the connecting films the greater is their adhesive force. Until the characteristics of materials in film phase are understood, the enormous cohesion furnished by films of molecular thicknesses cannot be visualized nor the full possibilities of soil stabilization realized.

To facilitate an understanding of the colloidal phenomena which serve as a basis for the intelligent formulation of methods of stabilization, there is presented the following digest, mainly from Bancroft [10] on the general theory of colloid chemistry as it applies to the cohesion furnished by films of submicroscopic dimensions in the soil.

MOISTURE IN FILM PHASE CAN GREATLY INCREASE SOIL STABILITY

All solids tend to adsorb or condense on their surfaces any gases or vapors with which they are in contact. Adsorption is specific and varies with the nature of the gas and of the adsorbing solid. With the same solid and the same gas the amount of adsorption is greater the higher the pressure of the gas and the lower the temperature.

If a liquid is adsorbed at a solid surface, it forms a liquid film there and thus wets the solid. For a liquid to wet a solid in the presence of air the liquid must be adsorbed more strongly than the air and must displace the air.

During a period of drought, drops of rain will often roll along the dust without wetting it. Even in the case of a shower the dust may be only wetted to a depth of less than ¼ inch. This has been shown to be due to the adsorbed air on the surface of the solid. Any treatment which cuts down the amount of adsorbed air makes the dust more easily wetted.

Some conception of the character of gas films is furnished by the thought that the transition of a pure liquid to its own vapor is not abrupt but that over a narrow range all the densities intermediate between those of vapor and of the liquid actually occur. One authority estimates the transition film for carbon dioxide at 20 ° C. to be 3 molecules or about 3 ten-millionths of an inch thick.

Williams [11] suggested in 1920 that the first layer of an adsorbed gas vapor may be under a pressure of as much as 10,000 atmospheres and have a corresponding density. From the first layer outward the density decreases to that of the liquid in bulk in the outermost layer.

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[10] Applied Colloidal Chemistry by W. D. Bancroft, McGraw-Hill Book Co., Inc., 1932.

[11] Proceedings of the Royal Society, vol. 98A, 1920, p. 223.

In like manner, the character of water changes with the size of the particle. Drops 1/40,000 of an inch to about 1/1,000,000 inch in size, when suspended in the air, appear as fog if you walk through them and as a cloud if you look at them from a distance. Under electrical stress they coalesce to form raindrops at sizes of about 2/1300 inch to 1/4 inch in size, which eventually become moisture films in soils.

So long as the soils are in a liquid or a plastic state, the films have in general the evaporation and freezing characteristics and the surface tension of water in bulk. When drying or mechanical compaction reduces the density of the soil below that at the plastic limit, the boiling point of the film rises, the freezing point lowers, and the surface tension increases so that these films become somewhat tougher than water in bulk.[12] This causes the soil to change from a plastic to a semisolid material. In thicknesses below 2/1,000,000 of an inch, the films behave, according to Terzaghi, like semisolid substances.[13]

The very fine vapor films have an adhesive power so great that they cannot be removed from glass by heating at a temperature up to 500° C. This high tenacity is utilized in the manufacture of frosted glass for use in office doors and windows. Rather thick glass is first coated with gelatine or glue. As the glue loses moisture it contracts, and the power of the gelatine is so great that it tears away the surface of the glass itself, chipping it into fern-like patterns. A brittle glue will give a different pattern from a tough glue, and the addition of salts also modifies the patterns.

That the properties of the minute moisture films approach those of semisolids instead of liquids accounts for the fact shown by Keen [14] that samples of sand grains with a binder of clay colloids can be 19 times as strong in compression as similar sand grains with an equal proportion of portland cement binder.

The theory of adhesion depends in part on the fact that the cementing material adheres strongly to the two surfaces and hardens there. For a given adhesive film and given materials the thinnest film gives the strongest joint. The thickness of films depends upon both the adhesive and the materials to be cemented. A slight change in the electrolytic properties of the latter is sufficient to cause a considerable variation in the thickness of the adhesive film and consequently in the strength of the resulting mixture of adhesive and aggregate.

According to Bancroft, Pettijohn [15] found about 5/1,000,000 of an inch for the maximum thickness of a water film on pearls made from one type of glass and 10/1,000,000 of an inch for pearls made from another type. With river sand the estimated thickness varied from 20/1,000,000 with 10-mesh sand to 5/1,000,000 of an inch with 60-mesh sand.

Methods utilized to obtain or maintain adhesive film strength in soils may be listed as follows:

1. Use of graded materials with granular material and binder of such character and in such proportions as to furnish the required pore size.
2. Treatment of road surface mixtures with deliquescent chemicals to stabilize the moisture content.
3. Densification of soil at optimum moisture content or treatment with chemical electrolyzers to facilitate the wetting of soil grains and decrease the thickness of the moisture films; use of bituminous materials to increase the cohesion and eliminate those properties of clay and colloids productive of detrimental volume change; and use of crystallizers to form water-resistant connecting films by hydration or base exchange.
4. Stabilization of the moisture content by waterproofing the soil with impervious surface treatments of bituminous materials.

WELL-GRADED MATERIALS HAVE CERTAIN ESSENTIAL FEATURES

Certain soils can be used to make a firm and hard road surface, capable of supporting the heaviest loads after long rains, free from mud or excessive dust, and which will carry traffic in both wet and dry weather without undue injury. Figure 1 is an example of such a surface.

Such materials are designated as hard or class A by Dr. Strahan and consist of coarse aggregate and soil mortar. The coarse aggregate is that portion retained on the no. 10 sieve and includes particles of natural gravel, supplemented when necessary with crushed stone or slag. Generally the largest particles should not exceed about 1 inch.

The mortar includes coarse sand or other granular material passing the no. 10 sieve and retained on the no. 60 sieve; fine sand passing the no. 60 sieve and retained on the no. 270 sieve; silt particles between 0.05 and 0.005 mm (0.002 inch to 0.0002 inch) in diameter; clay particles smaller than 0.005 mm in diameter; and moisture.

The coarse aggregate and coarse sand furnish structural strength and hardness; fine sand adds an embedment support to the coarse sand; silt acts as a filler to prevent the granular particles from rocking; and clay and colloidal particles provide pores minute enough to cause connecting moisture films which produce high cohesion.

Dr. Strahan called attention to the importance of the soil mortar as follows: "In judging these materials (road soils) full emphasis should be placed upon the soil mortar, i. e., material below no. 10 sieve. Weak soil mortars even with large amounts of coarse material often do not give proper stability under traffic."

In Dr. Strahan's reports clay is used to designate particles less than about 0.02 millimeter in diameter: silt, those particles with diameters between 0.02 and 0.07 millimeter; and sand, those particles larger than 0.07 millimeter in diameter.

In more recent work new size ranges have been adopted for several reasons:

1. The new sizes represent fractions having special physical significance. Particles larger than 0.05 millimeter have neither cohesion nor capillarity in appreciable amount; particles varying between 0.05 and 0.005 millimeter have considerable capillarity but little or no cohesion; and only particles smaller than about 0.005 millimeter can furnish cohesion.
2. The new sizes are used by the Bureau of Chemistry and Soils of the United States Department of Agriculture. The use of the same size ranges in highway work facilitates the use of the great amount of published information on soil surveys made by that bureau in which the mechanical analysis plays an important part.

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[12] Simplified Soil Tests for Subgrades and their Physical Significance, by Charles Terzaghi, Public Roads, vol. 7, no. 8, October 1926, p. 154.

[13] Physical Review, vol. 16, 1920, p. 56.

[14] The Physical Properties of the Soil, by Bernard A. Keen, Longmans Green and Co., 1931.

[15] Journal of the American Chemical Society, vol. 41, 1919, p. 477.

3. Prior to the development of the hydrometer method of analysis, the determination of the complete grading of the subsieve fraction was so laborious as to be impractical as a routine test for highway purposes. With the hydrometer method the grading according to the new sizes may be determined with no greater effort than was required for the determination of the grading by the old method of decantation.

Experience with soils indicates that they are stable only when they contain constituents which produce the following:

1. A certain total of seating and embedment stability together with the density required to resist traffic pressures and impacts.
2. An internal bond developed from interlocking grains and capillary moisture forces sufficient to cause the coarser sizes of sand and the coarse aggregate to have high stability during wet weather when the cohesion furnished by the clay may be greatly reduced.
3. Sufficient cohesion in the binder to cement the sand and silt when in a dry or almost dry condition and thus maintain the integrity of the surface during dry weather.
4. A surface which maintains constant volume, that is, there should not be so much clay that its expansion by water will break the seating and embedment bond of the granular particles.
5. Rapid evaporation to prevent the accumulation of capillary moisture from the subgrade beneath and active percolation to dispose of the rain water which may collect on the roadway in spite of efforts to maintain a smooth surface for the prompt removal of water.

The design of soil mixtures to provide these conditions is now based on the grading of the entire soil sample as determined by mechanical analyses, and on the binding properties of the fines as disclosed by plasticity tests performed on the fraction of soil passing the no. 40 sieve.

Materials falling within the following composition limits, by weight, should produce good results:

Passing—	Percent
1-inch screen	[16] 100
¾-inch screen	85–100
No. 4 sieve	55–85
No. 10 sieve	40–65
No. 40 sieve	25–50
No. 270 sieve	10–25

The fraction passing the no. 270 sieve should be less than two-thirds of the fraction passing the no. 40 sieve. Depending upon moisture conditions as discussed below, the fraction passing the no. 40 sieve shall have a plasticity index between 1 and 15 and a liquid limit not exceeding 35 as determined by physical tests made according to the methods of the Bureau of Public Roads.[17]

As early as 1922 Dr. Strahan called attention to the need for tests to disclose binding properties, suggesting that a highly colloidal clay in small amounts would evidently give adhesive strength equal to that produced by a large amount of less colloidal clay in a road soil mixture.

Another important indication was furnished by the work of the late Raymond Smith of the Ohio Department of Highways. Working with Prof. F. H. Eno of Ohio State University in constructing traffic-bound roads, he found that the stabilizing of material consisting principally of rounded particles, was greatly facilitated by additions of crushed materials or granulated slag.

As an additional guide, the field moisture equivalents may serve to indicate the tendency of binders to soften under conditions producing high moisture contents. In this connection values of 20 and less, 20 to 25 and greater than 25 indicate respectively the best, the medium, and the poorer materials.

PLASTICITY TESTS INDICATE BOTH CAPILLARITY AND COHESION

All cohesive soils have capillary properties but all soils with capillarity do not have cohesion. Liquid limits up to about 20 or slightly more generally indicate sandy materials with negligible capillarity. The more the liquid limit exceeds this amount the greater is the capillarity of the material. The plasticity index indicates the cohesion of materials but does not indicate their capillarity. Therefore the greater the plasticity index for equal liquid limits, the greater the cohesion of the material.

The properties of a mixture consisting largely of a relatively inert material such as ground quartz may be considerably changed by admixtures. As more active constituents are admixed the properties become those of the highly capillary diatoms, the moderately cohesive kaolin or the highly plastic colloidal bentonite. There are definite relationships between the test results and the percentages of the constituents which furnish the characterizing properties of soils. This is illustrated in figure 3.

The relationships between the liquid limits, *LL*, the plasticity indexes, *PI*, and the percentages of the active constituents, *P*, in mixtures of active materials and inert quartz are as follows:

For diatoms, $PI=0.21P=0.19\ (LL-18)$.
For kaolin, $PI=0.15P=0.71\ (LL-18)$.
For bentonite, $PI=3.3P=1.0\ (LL-18)$.

If any particular amount of cohesion is desired, say that indicated by a plasticity index of 5, the admixture according to these formulas may be 24 percent of diatoms, 33 percent of kaolin, or 1.5 percent of bentonite. The corresponding capillarities will be those indicated by a liquid limit of 44 for the mixture containing diatoms, 25 for the kaolin mixture, and 23 for the bentonite mixture.

In like manner the percentage of soil binder together with the accompanying capillarity to produce a desired plasticity can be determined by means of data furnished by the plasticity tests. The amount of inert material required to reduce excessively high plasticity can also be determined from similar data.

Generally plasticity indexes of about 3 or less indicate sufficient binder cohesion for use in road construction under unusually wet conditions; 4 to about 8, under conditions of average moisture; and 9 to 15 inclusive, only under dry or arid conditions. Plasticity indexes exceeding 15 indicate soils not suitable for road surfacing.

The presence of the undesirable micaceous, diatomaceous, peaty, or other organic substances is indicated when the liquid limit is greater than $1.6\ PI+14$.

The more the liquid limits exceed this value the more unsatisfactory the soil binder is apt to be due to detrimental sponginess and capillarity. Such properties will not be present in detrimental amount when the liquid limit does not exceed about 35.

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[16] Material of greater maximum size can be used under certain conditions but the largest aggregate should never exceed ⅓ the thickness of the stabilized layer and not more than 10 percent of the material should exceed 1 inch.

[17] Procedures for Testing Soils for the Determination of the Subgrade Soil Constants, by A. M. Wintermyer, E. A. Willis, and R. C. Thoreen. Public Roads, vol. 12, no. 8, October 1931.

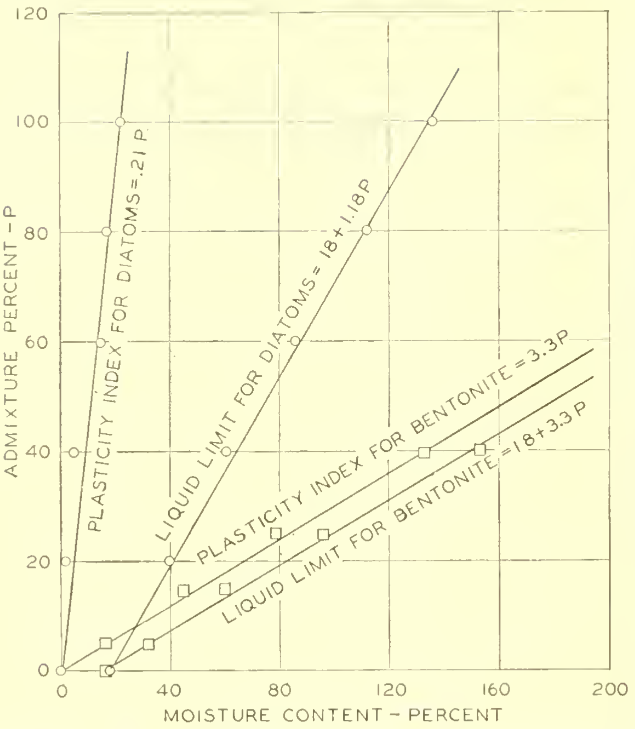

Figure 3.—Relation Between Percentage of Admixture of Inert Material and Plasticity Limits.

DELIQUESCENT SUBSTANCES USED TO PREVENT EXCESSIVE LOSS OF MOISTURE IN DRY WEATHER

Absence of moisture films from soil road surfaces causes dust and raveling; too much moisture causes rutting. The dryer a road surface becomes as a result of evaporation, the wetter a rain will make it. This is because extreme dryness causes small cracks and fissures to form in the clay binder through which rain water may enter and soften the interior of the road surface. Fissures do not form in damp surfaces of properly selected constituents and water will be shed from the surface without injurious effect.

Dampness of surface is desirable for another reason. All types of topsoil, gravel, traffic-bound and even water-bound macadam road surfaces acquire their final consolidation through compaction by traffic during what might be termed a period of seasoning following construction. When the surface is dry during this period the mineral binder powders under traffic and permits raveling of the surface, which requires extensive patching of the macadams and maintenance by means of mulch on the other types.

If such surfaces can be maintained in a damp or slightly moist state the moisture films in the minute pores of the binder will prevent the separation of the granular particles and the shocks and blows produced by traffic become effective in gradually wedging the granular fragments into close association. The cohesion increases as the pores in the binder become smaller and finally the coarse aggregate, the sand, the filler, and the binder are formed into a stable, durable road structure.

Calcium chloride is the principal chemical used in this type of stabilization although common salt has been used to a limited extent in experimental sections.

As early as 1907, Austin Thomas Byrne[18] discussed the use of sea-water and deliquescent salts for the suppression of dust.

The writer used calcium chloride as a dust layer on short sections of macadam streets in Pennsylvania about 1912. The value of this substance as a dust layer for gravel roads was quite generally recognized by 1916.

Sodium chloride has not received as much attention as calcium chloride although its possibilities were suggested by R. H. Phillips in 1919.[19] It was used in experiments on the Wendover cut-off in 1924[20] and in Nova Scotia in 1931.[21]

A report resulting from an investigation of calcium chloride as a dust palliative by the Highway Research Board,[22] first suggested the possibilities of this chemical for stabilizing the moisture content of graded materials in low type roads. This investigation included observations and tests on experimental roads in South Carolina, Missouri, and Nebraska. Supplemental tests were made to obtain quantitive data on the rate of evaporation from treated and untreated soil samples, the effect of rewetting surface on the rate of evaporation and on the leaching of calcium chloride by moisture.

CHEMICAL TREATMENT USED TO PRODUCE HIGH SOIL DENSITY

A recent report by W. R. Collings and L. C. Stewart[23] gives the results of traffic tests on test roads. This investigation included tests of various combinations of soils in road sections constructed on a large indoor track on an earth subgrade.

The track was oval in shape with straight sections 120 feet long and 12 feet wide and banked curves of 40 feet radius on the ends. The individual test sections were 25 feet long and 10 feet wide. A sprinkling system and hot air blown over the road surfaces were used to produce wet and dry road conditions. Mixtures for the test sections were prepared by combining various proportions of natural silts, clay, and fine and coarse aggregates. The materials were thoroughly mixed and deposited on the subgrade. The compaction was obtained by operating trucks over the test sections. In all, there were 28 test sections included in this investigation. Encouraging results furnished by these large-scale experiments were followed by the construction of the so-called stabilized soil road surfaces in a number of States, with the largest mileages in Michigan, Indiana, and Onondaga County, N. Y.

The Highway Research Board's investigation disclosed, among other things, that calcium chloride placed upon the surface retards the evaporation of soil moisture and that the moisture film cohesion furnished by calcium chloride is more stable than that furnished by plain water. It also showed that during periods of low rainfall and high temperatures the sections treated with calcium chloride have the higher moisture content and that calcium chloride is retained best in compacted and undisturbed surfaces.

The primary reason for the decrease in rate of evaporation is the low vapor pressure of the calcium chloride. A layer of the solution on the surface of the soil particle may be conceived of as an effective semipermeable blanket through which the moisture from the soil has difficulty in reaching the surface where evaporation takes place.

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[18] Treatise on Highway Construction, 5th edition, by Austin Thomas Byrne, John Wiley and Sons, New York, 1907, pp. 901–911.

[19] Salt-Marsh Sand Clay as a Road-Building Material, Engineering News-Record, vol. 82, no. 12, Mar. 20, 1919, p. 575.

[20] A Salt Dressing for Roads, Kentucky Road Builder, vol. 3, no. 10, Oct. 1924, p. 8.

[21] Nova Scotia's Experience with Dust Layers, by Percy C. Black, Canadian Engineer, vol. 61, no. 13, Sept. 29, 1931, p. 94.

[22] Report of Investigation of the Use of Calcium Chloride as a Dust Palliative, by Fred Burggraf, Proceedings of the Twelfth Annual Meeting of the Highway Research Board, Part 2, 1932.

[23] Stabilized Soil-Bound Road Surfaces Part 2: Traffic Tests of Trial Roads, by W. R. Collings and L. C. Stewart, Engineering News-Record, vol. 112, no. 23, June 7, 1934.

The hygroscopic property of calcium chloride causes absorption of moisture from the air during periods of high humidity and also slows up the rate at which soils lose moisture.

The high density attained during compaction by traffic is indicated by dry weights of as much as 150 pounds per cubic foot, which have been observed for wearing courses treated with calcium chloride and common salt. Retention of the material in the highly compacted state accounts for the beneficial action of the chemical upon the preservation of the road material.

MOST STABLE SOIL MIXTURES CONTAIN COARSE MATERIAL

The plasticity constants and the grading of a number of soil mixtures are shown in table 2. Mixture no. 1 shows the requirements of good mixtures as suggested on page 277 of this report. Mixture no. 2 represents the requirements of good soil mortars, based upon Dr. Strahan's work[24] assuming a coarse aggregate content of 50 percent. No. 3 is typical of the mixtures used in the construction of stabilized roads in Washtenaw County, Mich., in 1933.

Mixtures 4 to 8 are soil mortars studied by Collings and Stewart[25] in their investigation of the stability of various mixtures and the use of calcium chloride under controlled truck traffic. Mixtures 9 to 13 are of the sand-clay gravel type from the same experiments and were considerably more stable than mixtures 4 to 8. This is in line with Dr. Strahan's findings: "When coarse material is added to a good soil mortar in appreciable amount (10 percent or more) the hardness and durability of the surface is increased and continues to increase until a full gravel-type surface is reached."

Mixtures 14 to 17 are from the report on investigations by Travers and Hicks of stabilized roads in Onondaga County, N. Y.[26] Additional investigations by Collings and Stewart[27] furnished data on mixtures 18 to 30. Mixture no. 40 is typical of surfacing material used by G. A. Rahn in Pennsylvania.

Of these 10 mixtures investigated by Collings and Stewart, only nos. 4, 5, 6, 9, and 10, which have some plasticity, are considered satisfactory for surfacing. Samples 14 to 17, inclusive, representative of satisfactory mixtures reported by Travers and Hicks, had somewhat more plasticity than the 5 satisfactory soils reported by Collings and Stewart.

Of the mixtures 18 to 39, inclusive, mixtures 23 and 24, with no plasticity, and mixtures 32, 33, 38, and 39 were the least resistant.

TABLE 2.—*Plasticity and grading of typical soil-road materials*

[All materials pass the 1-inch screen]

Mixture no.	Liquid limit	Plasticity index	Passing—				
			¾-in. screen	No. 4 sieve	No. 10 sieve	No. 40 sieve	No. 270 sieve
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1		1-15	85-100	55-85	40-65	25-50	10-25
2	14-35	4-8			50	26-34	8-15
3	20	6		73	50	38	17
4	16	1			100	75	16
5	15	4			100	77	27
6	15	1			100	73	22
7	16	0			100	77	13
8	17	0			100	76	7
9	17	4	100	72	39	25	12
10	15	3	100	62	40	29	16
11	13	0	97	53	39	22	11
12	13	1	100	78	56	33	13
13	12	0	100	69	43	20	10
14		8	98	63	51	31	14
15		7	98	73	63	39	23
16		5	97	52	39	24	17
17		7	98	65	53	28	10
18	27	14	82	57	50	41	20
19	22	11	82	58	51	43	20
20	21	10	80	56	48	38	14
21	17	5	79	54	46	36	11
22	18	5	79	54	46	34	10
23		0	82	57	50	38	10
24		0	79	54	45	34	6
25	28	15	95	68	54	46	24
26	22	11	100	68	53	45	23
27	21	10	100	77	59	48	22
28	27	15	100	71	53	43	28
29	22	11	94	64	47	39	16
30	17	6	94	64	46	36	14
31	27	15	100	70	50	38	18
32	20	10	100	71	52	40	15
33	18	6	94	65	47	56	10
34	21	10	96	77	65	53	26
35	27	15	96	77	66	58	36
36	21	10	94	65	49	40	19
37	27	15	94	63	48	41	24
38	20	10	92	57	39	28	14
39	28	15	92	52	33	28	17
40	22	5	97	66	59	46	20

The manner in which local materials are selected for use in soil roads was excellently described by G. A. Rahn, of the Pennsylvania Department of Highways, before the 1934 convention of the American Society for Testing Materials. In one case the soil of the original road was taken to the laboratory and on test was found to be a silt loam. Since stone screenings were available near the location of the road for use as admixture, tests were made to determine the amount of admixture required to change the soil to the more stable A-2 type. With this information as a guide the screenings were applied to the old road and worked in until tests disclosed the proper amount had been added. Some time later calcium chloride was applied to the surface. The illustration, figure 4, was taken in April 1934 and shows the manner in which the stabilized road came through the winter in comparison with the side road which was not stabilized. Mixture 40 of table 2 is representative of the mixture used.

Calcium chloride is applied to soil surfaces at the rate of about one-half pound per square yard per inch of thickness of road surface and preferably should be mixed with the graded surfacing material. Indiana requires not less than three-fourths of a pound of common salt per square yard per inch of surface thickness with the additional requirement that the salt shall be applied in a solution of about 8 pounds of salt to 5 gallons of water.

The chemically treated surfaces are firmly bound and offer great resistance to raveling under traffic. Smoothness is maintained without the loose surface mulch often used on untreated gravel roads. In fact, the presence of mulch may act as an abrasive under the wheels of vehicles and thus prove detrimental.

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[24] Subgrade Soil Constants, Their Significance, and Their Application in Practice, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Willis, Public Roads, vol. 12, nos. 4 and 5, June and July, 1931.

[25] Report on Investigations of the Use of Calcium Chloride as a Dust Palliative, discussion by L. C. Stewart and W. R. Collings, Proceedings of the Twelfth Annual Meeting of the Highway Research Board, Part 2, 1932, p. 45; see also Improved Low Cost Soil and Gravel Roads, The Dow Chemical Co., 1933.

[26] Gravel Type Surfaces for Secondary Roads, by Ray B. Travers and W. B. Hicks, Proceedings of the Thirteenth Annual Meeting of the Highway Research Board, Part 1, 1933, p. 228.

[27] Stabilized Soil-Bound Road Surfaces, Part 2, Traffic Tests of Trial Roads, by W. R. Collings and L. C. Stewart, Engineering News-Record, vol. 112, no. 23, June 7, 1934.

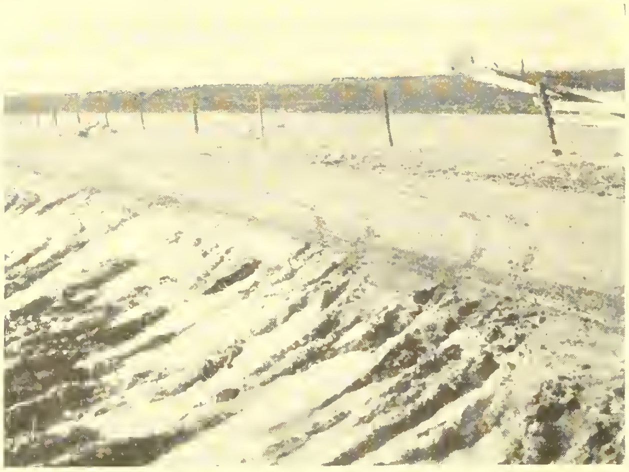

FIGURE 4.—STABILIZED ROAD IN ADAMS COUNTY, PA., AT ITS JUNCTION WITH UNTREATED SIDE ROAD.

A good mixture for the repair of areas in which pitting has occurred consists of aggregate under one-half inch in size, mixed with at least an equal weight of stable sand-clay. To insure that the patching materials will be moist enough to stick securely in the hole, the admixture of 100 to 150 pounds of calcium chloride per cubic yard is recommended.

Figures 5 and 6 illustrate steps in the construction of roads treated with deliquescent chemicals in Michigan. Figure 7 shows similar surfaces in Indiana.

PERMANENT DENSIFICATION OF SOILS A PROMISING BUT LITTLE-EXPLORED METHOD

The purpose of this type of stabilization is to produce a semisolid and dense soil-road surface which is not affected by moisture and is capable, when suitably surface treated, of serving a considerable volume of traffic. The method is suitable for use where only fine-grained soils abound as well as in those locations having granular materials and binder available for use in graded soil mixtures.

The idea of stabilizing soils by means of admixtures of other than soil materials is not new. Prof. F. H. Eno used both hydrated lime and portland cement as admixtures to improve subgrade soils in experimental sections in 1924 and 1925.[28]

More recently, in 1929, Prof. Eno used salt, hydrated lime, calcium chloride, sodium silicate, kerosene, cold tar, crude oil, and used crankcase oil in addition to stone dust and granulated slag in experimental sections of subgrades of six traffic-bound roads in Ohio. The treatments were carried to a depth of 3 inches in the subgrade.[29]

It was not until 1932, however, that the importance of densification in connection with the use of chemical admixtures began to be realized. From experiments performed at the Arlington laboratory of the Bureau of Public Roads it became evident that when soils were treated with such materials as portland cement, bituminous materials, etc., the stabilizers could best be distributed in fine-grained soils in the form of solutions or emulsions. However, samples thus treated became porous upon drying due to the effect of the admixtures in reducing the shrinkage properties of the colloids. Thus the necessity of including mechanical compaction as part of the stabilizing procedure became evident. Experimentation was begun on procedures for compacting samples and determination of the properties of samples thus prepared.

Figure 8 shows an apparatus devised for bringing an entire sample, including the coarse fraction, to various degrees of consolidation. The apparatus is based on the principle of the sheepsfoot roller, and it appears that compaction according to this principle will be desirable in construction. Samples having various degrees of consolidation have been tested for permeability, capillarity, stability, and shrinkage.

In 1933 a definite basis was established for the intelligent incorporation of admixtures in soils; a means was provided for determining the amount of compaction required; and a method was suggested for evaluating in the laboratory the relative stabilizing effects of the various admixtures. R. R. Proctor, of the Los Angeles Bureau of Waterworks, is largely responsible for these contributions.[30]

In 1925 Milburn[31] showed that there is an optimum binder content at which maximum density of bituminous mixtures may be attained, and in 1928 Jackson[32] pointed out that concrete investigators accepted the conclusion that there is an optimum water-cement ratio for each portland cement concrete mixture. Proctor, in a series of reports, has shown that for every soil there is a moisture content at which maximum compaction can be obtained with a sheepsfoot roller during construction. The extent of this compaction is readily ascertained by testing samples at different moisture contents under impacts of a standard tamper in the laboratory.

LABORATORY TESTS SHOW IMPORTANCE OF PROPER MOISTURE CONTENT IN PRODUCING MAXIMUM DENSITY BY COMPACTION

Figures 9, 10, and 11[33] illustrate the apparatus and the significance of the Proctor tests. The soil samples are compacted at different moisture contents in a one-thirtieth cubic-foot cylinder by the impact of a 5½-pound rammer in such a manner as to duplicate the force obtained by a sheepsfoot roller in the field. The density of the compacted soil is computed from the actual weight of soil and the moisture content and expressed in pounds of soil per cubic foot. The bearing power of the compacted soil is determined for each moisture content by measuring the force needed to push a needle of known end-area into the soil at a speed of one-half inch per second.

Figure 9 shows the compacted fill material being tested with the plasticity needle. In the background is the type of sheepsfoot roller used to compact the fill.

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[28] Highway Subsoil Investigation in Ohio, by F. H. Eno, Engineering Experiment Station Bulletin No. 39, Ohio State University, 1928.

[29] Subgrade Drainage and Treatment by F. H. Eno, Proceedings Eleventh Annual Meeting of the Highway Research Board, 1931, p. 192.

[30] Fundamental Principles of Soil Compaction, by R. R. Proctor, Engineering News-Record vol. 111, no. 9, August 31, 1933; Field and Laboratory Determination of Soil Suitability, by R. R. Proctor, Engineering News-Record, vol. 111, no. 10, Sept. 7, 1933; Field and Laboratory Verification of Soil Suitability, by R. R. Proctor, Engineering News-Record, vol. 111, no. 12, Sept. 21, 1933; New Principles Applied to Actual Dam Building, by R. R. Proctor, Engineering News-Record, vol. 111, no. 13, Sept. 28, 1933.

[31] A Deformation Test for Asphaltic Mixtures, by H. M. Milburn, Public Roads, vol. 6, no. 6, August 1925.

[32] The Design of Pavement Concrete by the Water-Cement Ratio Method, by F. H. Jackson, Public Roads, vol. 9, no. 6, August 1928.

[33] These figures supplied by C. A. Hogentogler, Jr., soils engineer, Back Creek Earth Dam Project, U. S. Forest Service.

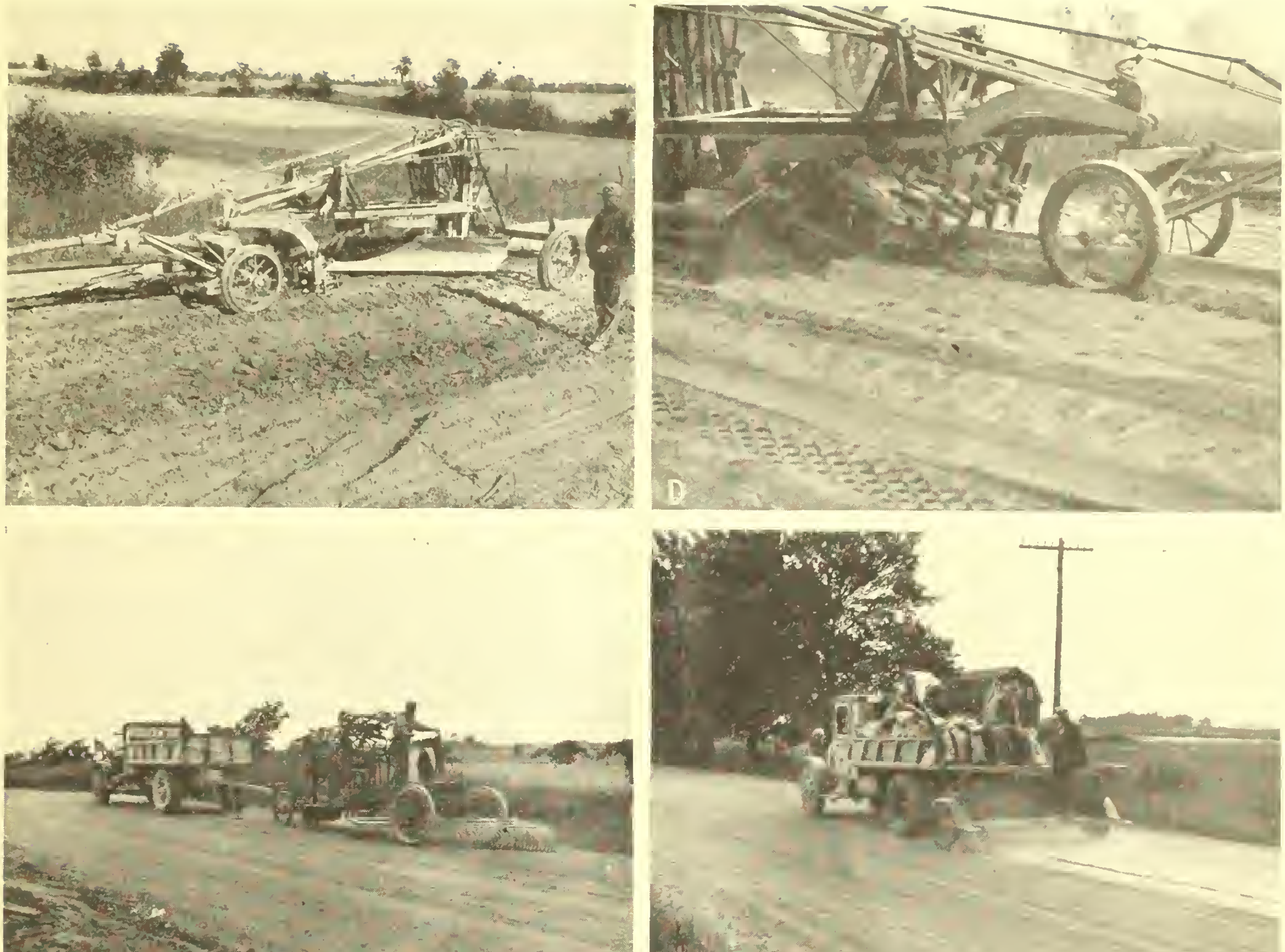

Figure 5.—Steps in Soil Road Construction in Michigan. A, Scarifying Old Surface; B, Removing Large Stone with Rake; C, Spreading Pulverized Clay Admixture; D, Deep Blading to Mix Clay with Old Road Material; E, Spreading Chemical Over Smoothed Surface; F, Mixing by Blading in Windrows.

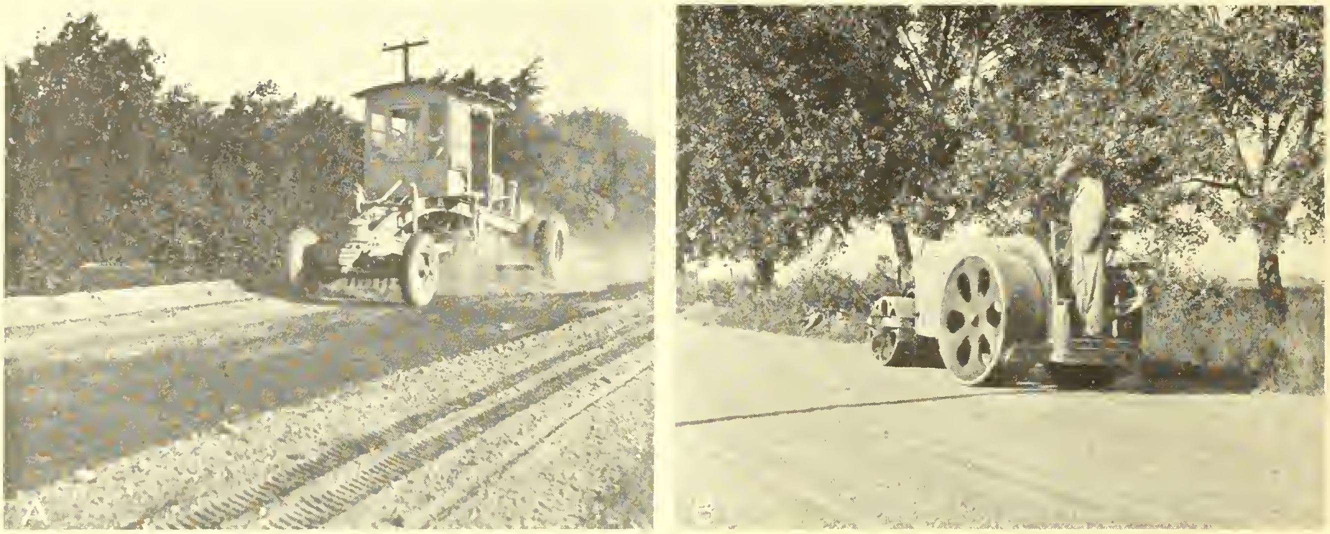

Figure 6.—A, Spreading Dry Material Over Wetted Road Bed; B, Rolling the Partially Dry Surface.

Figure 7.—Soil Surfaces in Indiana Containing Deliquescent Chemicals.

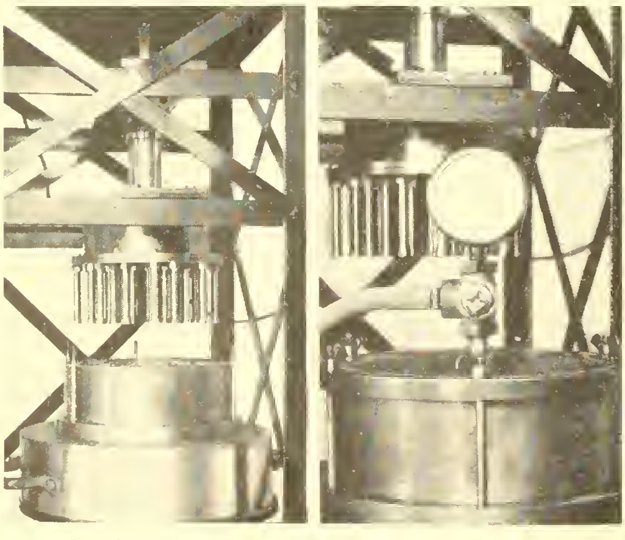

Figure 8.—Apparatus for Consolidating Sample and Testing for Permeability, Capillarity, and Shrinkage.

Figure 10 shows the two curves resulting from the test; the weight of dry soil-moisture content relation and the bearing value-moisture content relation. The weight of dry soil-moisture content curve discloses that for this soil a moisture content of about 19 percent is required if maximum compaction is to be attained. The corresponding bearing value is about 1,100 pounds per square inch.

If, at the specified compaction, the bearing value of this particular soil is indicated by the plasticity needle to be higher than 1,100 pounds, the increase can be considered as only temporary if the fill is to be unprotected from water after construction. Thus a bearing value of 1,600 pounds per square inch indicates a moisture content of slightly less than 17 percent. This corresponds to a dry weight of about 106 pounds per cubic foot. At this density the soil can take up moisture to a maximum of slightly more than 20 percent which, in turn corresponds to a bearing value of but 600 pounds per square inch.

Figure 11 illustrates how dry weight-moisture content curves may be used to disclose the effect of various admixtures in increasing or decreasing the stability of soil. It is shown that some admixtures serve to increase the optimum moisture content, others tend to

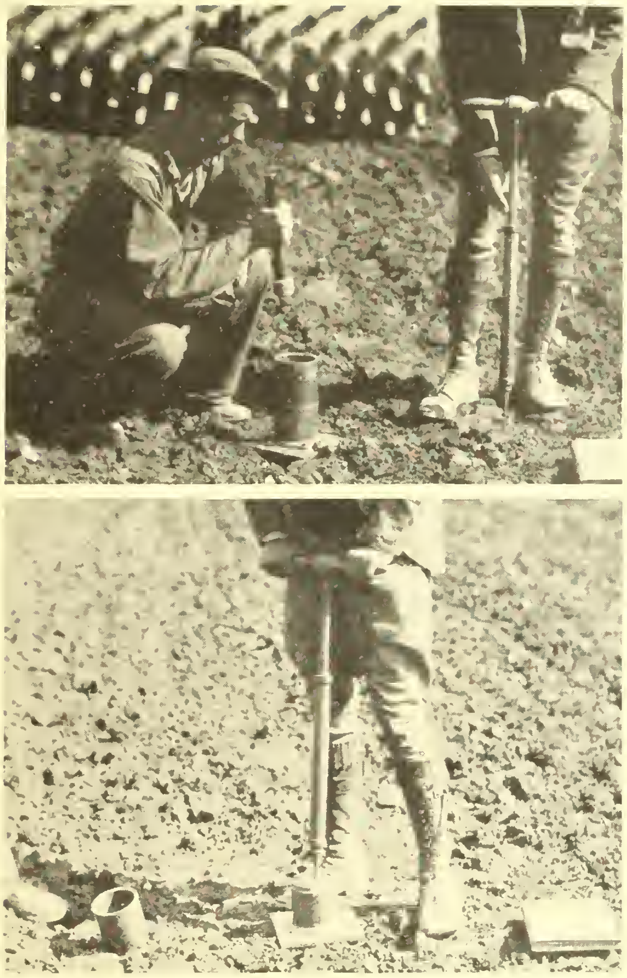

Figure 9.—Compacting Soil in Proctor Cylinder and Determining Consistency of Fill with Plasticity Needle.

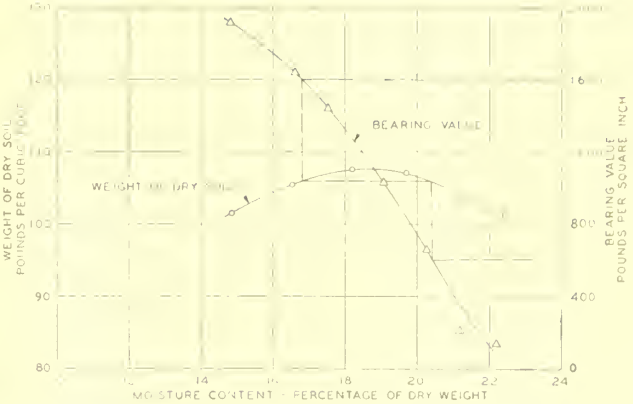

Figure 10.—Data Furnished by Proctor Tests.

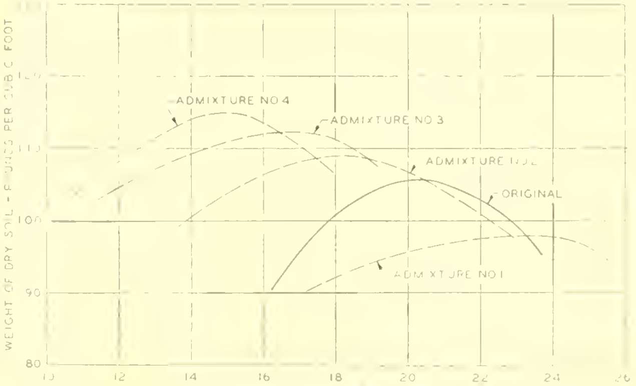

Figure 11.—Effect of Chemical Admixtures in Reducing Optimum Moisture Content and Increasing the Density of Compacted Samples.

decrease it. As the optimum moisture content increases, the maximum density decreases.

By incorporating certain elements of the Proctor tests in a modified compression and permeability test, it seems possible to predetermine how well soils with admixtures, compacted according to current construction methods, will retain a high density under varying climatic and load conditions. The procedure is to compact the sample at optimum moisture content and then transfer it in the compacted state to the Terzaghi compression test apparatus and observe the compression and expansion characteristics.

The results of such tests are shown in figure 12, upper left. This curve is representative of one of the most troublesome of subgrade soils—due to shrinkage and plasticity—the highly colloidal, sticky, tenacious soil in zone B of the Iredell series. The curve shows that maximum density is reached at a moisture content equal to about 16 percent of the weight of the dry soil. At this moisture content a density indicated by a dry weight of 106 pounds per cubic foot is obtained. Results of compression and expansion tests on a sample of soil compacted at this moisture content are shown in the lower left of figure 12. The sample was placed in the apparatus, without having access to water, and a load applied in increments up to 8.2 tons per square foot. The load was then reduced to 0.05 ton per square foot. The results are shown by the broken lines. Water was then allowed to enter the testing apparatus and after a considerable interval of time the load was again increased to 8.2 tons per square foot and then reduced to 0.05 ton per square foot. These results are indicated by the full line which represents both load application and load removal.

Figure 12, C, D, and E shows results of similar tests on samples of the same soil in dust phase, at optimum moisture content but uncompacted, and on a sample wetted to about the liquid limit. In these curves volume change is indicated by the voids ratio. The small change in volume of the compacted sample resulting from wetting and change in load, as compared with that of the same soil in the other states, is striking. This is further emphasized by figure 13 which shows the same test results in terms of thickness of soil layer per unit thickness of solids in the layer.

The results shown in figure 13 indicate that subgrades comprised of the highly plastic soils, such as the black waxy soils, the adobes and the gumbos, when manipulated at the proper moisture content, may be compacted to high densities which will remain fairly constant under widely changing conditions of load and access to water.

The consolidations shown were produced by load periods of 72 hours on samples about 1 centimeter thick. Expansions were measured after loads had been removed for periods of 24 to 48 hours. To produce an equal degree of consolidation in soil layers thicker than 1 centimeter, the duration of the load would vary as the square of the thickness of the layer.

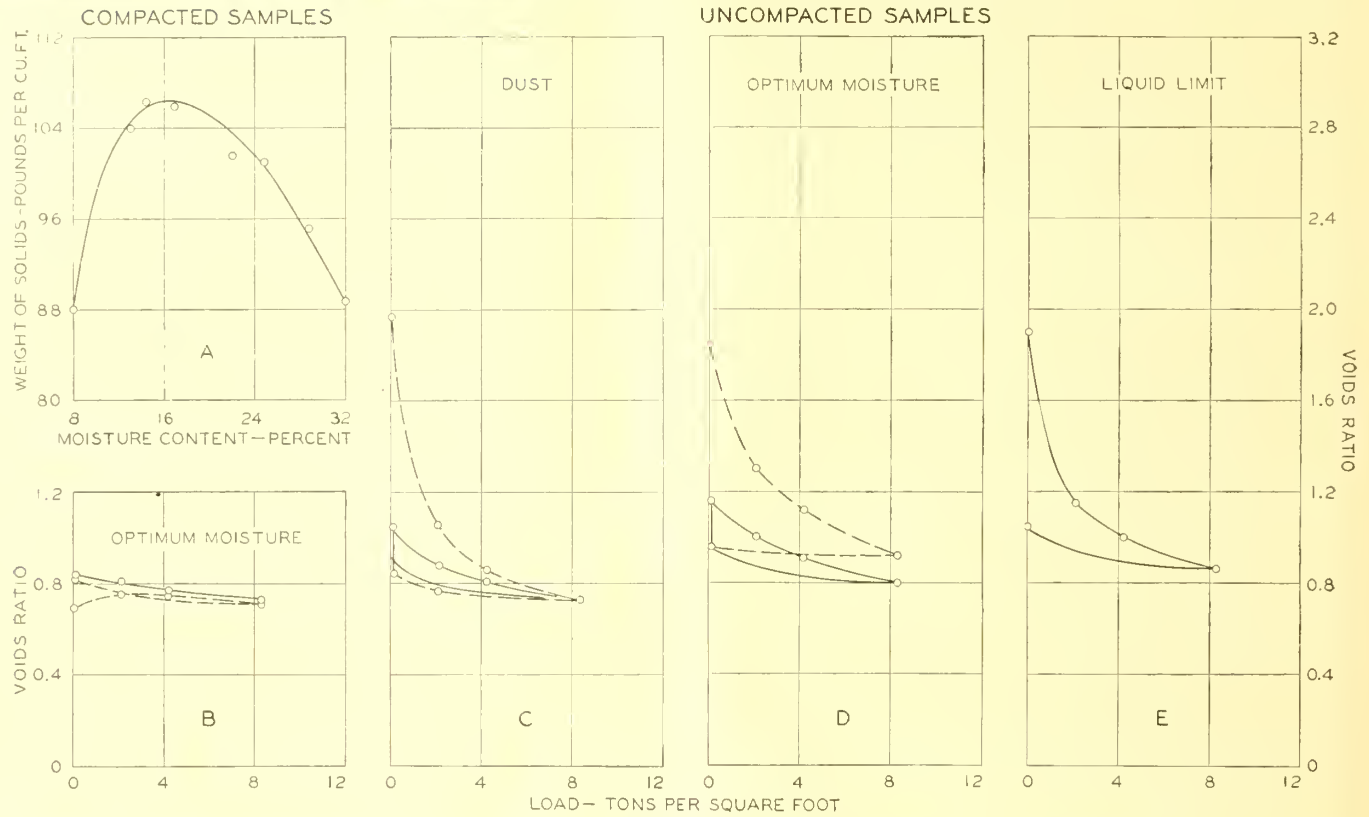

Figure 12.—Relation Between Moisture Content and Density after Compaction of Iredell Clay and Results of Compression Tests on Compacted and Uncompacted Samples.

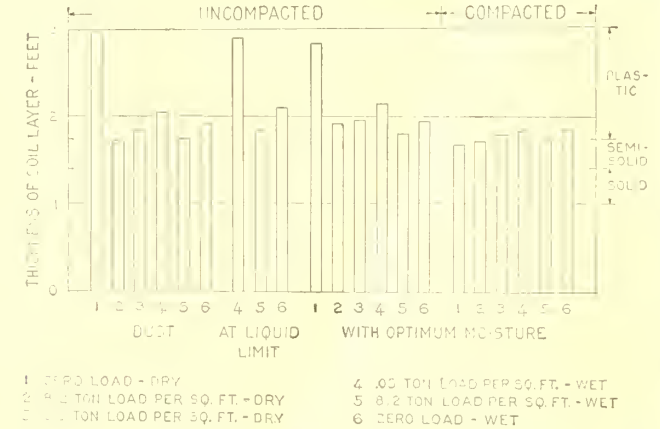

Figure 13.—Thickness of a Layer of Iredell Clay Containing the Equivalent of 1 Foot of Solids Under Different Test Conditions. The Terms "Wet" and "Dry" Refer to Conditions Surrounding the Sample.

APPLICATION OF SURFACE CHEMISTRY TO SOIL STABILIZATION BEING STUDIED

The great possibilities in the application of surface chemistry to soil stabilization are indicated by the reports of Winterkorn,[34] Reagel and Schappler,[35] of the Missouri State Highway Department. Their work discloses that some bases have greater affinity for bitumen than for water and that the reverse is true for other bases. The use of soap as an electrolyzer facilitates the mixing of some soils with bituminous materials. The benefit of the soap treatment was demonstrated in an experiment in which soap was used on one section of an earth-gravel-oil mixture and omitted on another section. A heavy rain washed the oil from the latter section but did not wash it from the soap-treated section. It is indicated that different soaps may be desirable for different soils. Ions from different bases may either increase or decrease shrinkage, plasticity and other properties on which stability depends. For every soil it is possible to select a cation for exchange which will adjust the properties of the soil as desired.

Among the substances suggested as having possible use as admixtures in soil densification are bituminous materials, portland cement, hydrated lime, calcium chloride, calcium silicate, calcium carbonate, soda ash, sodium silicate, and sodium chloride.

It is believed that the high densities of road surfaces treated with calcium chloride and salt are not due entirely to the deliquescence of these materials but are in part due to electrolytic effect in reducing the thickness of the moisture films. A limited number of compaction curves, such as shown in figure 11, support this conclusion.

It is possible that chemicals such as calcium chloride and common salt, which serve to lower the freezing temperature, might be beneficial in the colder climates in their effect on freezing.

STABILIZATION BY SURFACE TREATMENTS EFFECTIVE ONLY FOR SOILS OF GOOD QUALITY

The preceding discussion discloses methods of determining densities which can be produced by special methods and which can be maintained under a wide range in moisture and load conditions. The maintenance of high density in a road surface, however, requires that subgrades and bases for thin wearing courses be constructed in such a manner as to prevent damage by water coming from beneath the surface and also that loss of moisture from the densified soil by evaporation be prevented. It is because of this requirement that a discussion of the benefits of waterproofing by surface treatment is included in this report.

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[34] Oiling Earth Roads, Application of Surface Chemistry, by Hans Winterkorn, Industrial and Engineering Chemistry, vol. 26, August 1934.

[35] Stabilizing Sand and Gravel Surfaces, by R. C. Schappler, Kansas Highway Conference, Manhattan, Kans., Feb. 5, 1934.

Two conditions are essential if the waterproofing of a soil surface is to be worth while. The materials of the surface and base must be either impervious enough, or have sufficiently low capillarity to prevent the accumulation of enough capillary moisture to cause instability. The quality of materials necessary will be affected by climate, topography, and traffic. The surface treatment must be maintained sufficiently impervious to prevent the surface water entering clay soils from above and to prevent the evaporation of the cohesive moisture films from sandy soils.

Stabilization by surface treatment is excellently illustrated by the blotter-type tar and asphalt surface treatments on the heavy gumbo soil roads of western Minnesota and eastern North Dakota.[36] The top view of figure 14 shows a condition in the spring of a road west of Ada, Minn., prior to the first treatment in 1924. Gravel used for surfacing was found to have penetrated to depths as great as 3 feet. The lower view of figure 14 is a picture taken in the spring of the year and shows the condition of a similar road after receiving a surface treatment of bituminous material with gravel covering. On inspection in 1932, the total thickness of the surface treatment was found to be slightly less than 1 inch.

Bituminous surface treatments have long been used in the Southern States to change loose sandy and dusty materials into firm, stable, durable road surfaces. Prevention of evaporation accounts for at least part of this benefit.[37]

LOW-COST ALL-WEATHER ROADS REQUIRED IN HIGHWAY PROGRAM

Only a small percentage of natural soils are of good quality for road surfacing. Even in Georgia, where soil conditions are particularly favorable, soils of the best quality are more the exception than the rule. Of 29 sand-clay Federal-aid projects reported by Dr. Strahan, but 3 had strong, hard surfaces, free from ruts, holes, or corrugations, indicative of class A material. Admixtures and chemical treatments are most often used to give low-grade materials those qualities naturally present in class A topsoils as a result of long cultivation and weathering and in well-graded gravels as a result of their composition. The admixtures and treatments have the additional advantage that they avoid the necessity of a dust-producing mulch surface.

Substantial progress has been made in the design of soil mixtures, and in the use of bituminous surface treatments and stabilization of the moisture content by means of treatment with deliquescent substances.

The tentative requirements for the design of stable mixtures given on page 277 are based upon extensive laboratory experiments, and observations of roads in service and represent a step toward the simplification of test procedure for identifying road soils for use in construction.

Selected soil surfaces are suitable for temporary surfacing on important roads. They can be placed immediately after the grading for use during the period of settlement and will give substantial support and increased life to pavements placed upon them.

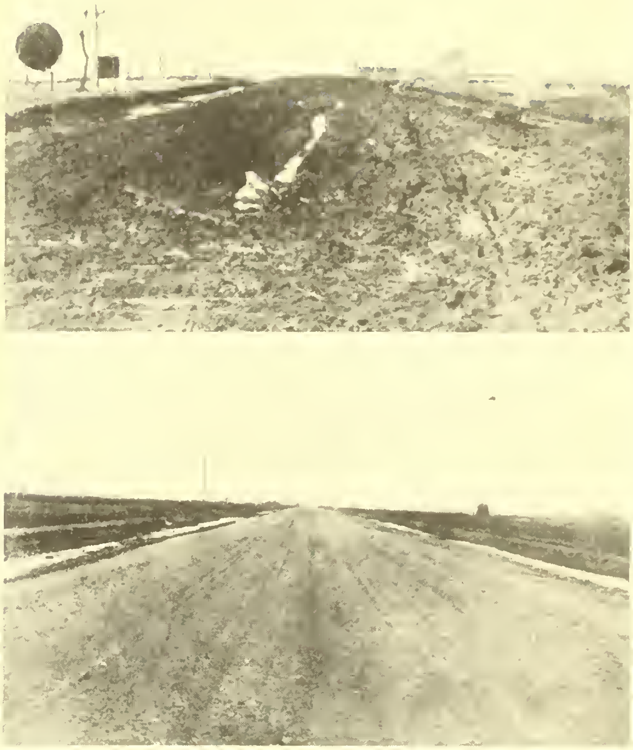
FIGURE 14.—A TYPICAL MINNESOTA GUMBO ROAD IN EARLY SPRING AND A ROAD ON SAME TYPE OF SOIL AFTER BEING TREATED WITH BITUMINOUS MATERIAL AND COVERED WITH A THIN LAYER OF GRAVEL.

The method of stabilization by densification at optimum moisture content has been utilized principally in connection with the construction of embankments for use as earth dams, although it is equally applicable for use in any kind of fill, subgrade or soil base-course construction.

Water attracted by the adsorptive affinity of soil particles for moisture cannot enter and soften the soil mass when the particles are covered with moisture films and the soil is compacted to maximum density at optimum moisture content. Under these conditions the tendency to expand and lose stability in the presence of moisture may be eliminated from highly plastic soils when protected by surface treatment. Densification will not be effective with soils in which the tendency to expand is due to elastic rebound such as those containing mica.

Field experimentation in the use of chemical admixtures which change the character of the soil include the use of portland cement, bituminous emulsions, and treatment with sodium silicate and calcium chloride in combination to produce calcium silicate precipitate.

Several sections of soil road stabilized with cement and given a bituminous surface treatment were constructed by the South Carolina State Highway Department during 1934. A bituminous emulsion was mixed with the soil in constructing an airport runway in Baltimore, Md. The use of the silicate-chloride method of treatment has been confined largely to the stabilization of soil supporting buildings and other structures.

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[36] Blotter Treatment of Gravel Roads in the State of Minnesota, by F. C. Lang, Eighth Annual Asphalt Paving Conference, 1929.

[37] Tar Surface Treatment of Low Cost Roads, Public Roads, vol. 14, no. 1, March 1933.

The stability furnished by compaction of soils at optimum moisture content suggests that vastly greater benefits may be expected when the interfacial colloidal films are stabilized by proper use of bitumen, portland cement, and the ions of sodium, potassium, and calcium.

New developments can be expected as progress is made in this vast and but little-explored field. The materials being investigated are low in cost and widely different in character. They are subjected to varying weather conditions and traffic loads. The results obtained should be evaluated on the basis of the benefit rendered by the stabilizing procedure in comparison with its cost.

More than 2,000,000 miles of rural roads are unimproved. On much of this mileage surfacing is not economically justified, but there is a considerable mileage which should be surfaced and the extent to which this is done will depend on the cost.

PUBLICATION ON TREE WOUNDS

Questions concerning the proper treatment of wounds in roadside, shade, ornamental, street, and park trees are considered in Farmers' Bulletin No. 1726 of the United States Department of Agriculture. The publication is intended primarily for persons in charge of public or private property with little or no knowledge concerning the normal processes of a healthy tree or why and how wounds endanger the health of trees.

The simpler types of treatment for tree wounds, the bulletin explains, are within the range of almost any practical man who is familiar with the use of a saw, gouge, mallet, and paintbrush. Two axioms that should be borne in mind constantly are (1) that proper treatment of fresh-made wounds is the surest and best method of preventing disease or decay and needless expense in the future, and (2) that all old wounds should be treated by some proper method. The practice of treating tree wounds is very old and, according to the bulletin, it is not a secret art, probably all of the best methods are well known.

The structure and life processes of trees are described and causes of injury discussed. What trees are worth treating, when the work may be done, and detailed methods are discussed. Numerous illustrations show the recommended methods of wound treatment.

Copies of this publication on tree wounds may be obtained free of charge from the Office of Information, United States Department of Agriculture, Washington, D. C., until the free supply is exhausted, or copies may be obtained for 5 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JANUARY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$3,947,753	$2,129,921	$5,225,767	$2,835,989	$35,889	294.6	$2,326,458	$976,738	$534,211	133.6	$58,042	$573,840	31.8	$76,984	$985,981
Arizona	3,878,555	1,338,712	4,346,144	3,697,024	49,025	290.8	975,791	157,724	789,185	68.2	4,655	116,880	15.7	19,152	383,622
Arkansas	3,334,167	1,714,000	2,891,476	2,306,771	137,101	152.0	1,301,464	881,319	194,072	36.0	39,563	844,227	47.8	106,514	538,600
California	7,912,928	3,713,643	9,080,780	6,828,601		277.2	3,177,682	1,076,204	881,600	51.6		941,950	39.5	8,123	1,890,093
Colorado	3,437,265	2,424,504	3,800,099	3,366,958	350,780	174.5	1,684,744	16,425	1,649,339	84.8	53,882	92,549	11.8		331,836
Connecticut	1,404,213	607,500	620,538	618,204		10.7	1,501,976	786,009	453,399	25.4		154,100	1.8		1
Delaware	892,544	461,697	877,890	873,987		33.4	465,318		450,140	15.4				18,557	11,557
Florida	2,519,011	1,116,600	2,845,504	2,091,539		103.4	742,834	350,264	273,046	27.4	3,231	511,958	21.0	73,977	331,595
Georgia	5,045,592	2,556,745	3,641,356	3,452,584		252.7	1,528,756	1,246,635	282,121	76.7	211,955	1,040,306	57.5	134,418	1,234,318
Idaho	2,166,858	1,131,910	2,152,272	1,984,973	97,326	184.1	533,694	171,151	350,349	28.1		81,272	13.3	10,734	602,964
Illinois	4,442,467	3,060,041	1,777,709	1,767,055		32.2	3,040,703	2,615,136	425,567	39.0	36,045	823,818	18.5	24,232	1,810,655
Indiana	5,018,921	2,843,478	3,066,653	3,052,979		102.7	1,916,356	1,915,616		38.0	50,326	939,387	117.8		1,904,091
Iowa	5,027,830	2,217,361	4,854,228	4,611,845	42,120	277.4	1,789,712	380,600	1,314,277	122.8		546,418	24.6	35,386	314,546
Kansas	5,044,802	2,558,837	5,306,941	4,936,822	162,941	536.9	1,425,666	56,400	1,369,266	151.9		1,021,307	66.6	51,580	5,324
Kentucky	3,751,605	1,527,324	3,626,938	3,358,981	33,571	243.9	606,582	260,655	293,774	49.7	109,476	355,126	37.3	22,493	844,853
Louisiana	2,711,152	1,380,419	1,756,275	1,752,495		73.9	1,833,571	905,474	406,070	11.9	44,383	674,906	11.9	8,800	299,442
Maine	1,617,560	793,644	1,352,859	1,317,292		43.8	805,536	239,455	566,081	13.5		197,402	6.8	60,813	30,161
Maryland	1,782,263	289,609	791,624	778,132	3,843	15.1	886,878	771,460	115,418	20.0	39,135	97,729	1.7	193,536	72,620
Massachusetts	1,101,716	1,632,874	1,409,030	1,016,079		37.4	493,554	52,687	389,045	9.2		433,106	3.3	32,950	810,723
Michigan	6,051,532	3,226,284	4,772,814	4,696,316		223.4	2,712,925	1,348,200	1,349,925	101.5		1,584,925	60.2	7,016	291,434
Minnesota	4,561,011	2,642,244	5,606,216	4,331,330	1,180,063	850.0	921,564	179,056	677,108	144.8		317,832	42.8	50,625	467,240
Mississippi	3,489,337	2,301,148	3,991,149	2,186,609		204.6	2,467,179	1,134,596	414,197	135.0	19,165	787,369	39.2	148,966	1,099,582
Missouri	5,237,532	2,132,426	4,652,876	4,118,028		187.9	2,170,258	813,729	1,058,737	68.7	293,639	765,427	20.7	12,136	308,262
Montana	4,463,849	2,714,208	5,266,931	4,435,113	190,457	394.7	1,652,792	4,129	1,579,705	189.2		805,333	47.0	24,607	138,713
Nebraska	3,914,481	1,982,182	5,112,823	3,892,837	42,406	371.7	1,298,005	21,644	953,818	58.3		949,886	51.4		36,071
Nevada	2,909,387	1,350,356	2,861,718	2,736,177	76,039	268.7	733,660	91,948	641,712	100.9	34,558	14,755	2.6	46,704	617,850
New Hampshire	725,739	484,731	638,684	612,389		10.8	425,572	79,730	324,780	11.2		133,511	1.3	33,620	26,440
New Jersey	3,173,019	951,379	1,711,841	1,692,308		31.6	1,488,098	1,296,101	24,919	15.4	175,941	103,000	2.6	8,669	823,461
New Mexico	2,846,648	1,676,769	3,029,320	2,760,948	124,443	297.5	1,078,627	17,929	1,060,698	91.6	67,771		5.0		491,628
New York	10,465,672	3,521,450	10,197,935	8,416,188	53,000	210.3	7,632,928	2,010,070	2,391,600	134.8		277,850	8.9	39,414	799,000
North Carolina	4,761,147	2,040,068	4,388,332	3,558,353	104,959	576.4	1,333,818	646,965	319,554	124.3	253,983	264,479	49.4	301,846	1,351,077
North Dakota	2,902,224	1,469,484	3,133,056	2,665,441	39,051	1007.7	329,512	53,772	215,946	117.4	40,312	476,769	264.2	142,700	737,716
Ohio	7,277,758	3,539,256	7,482,755	7,061,148		193.2	1,570,870	18,020	1,360,460	39.6		1,700,051	27.0	198,589	478,744
Oklahoma	4,608,399	2,342,590	3,659,685	3,581,276		272.9	1,541,939	758,239	754,977	69.4	258,976	1,037,521	54.9	9,908	550,092
Oregon	3,053,448	1,452,741	3,334,673	3,017,287		183.0	1,146,893	13,619	1,076,274	48.8		84,352	8.2	22,542	292,115
Pennsylvania	6,691,194	4,554,082	5,533,040	5,339,313	17,389	120.0	3,910,648	1,250,052	2,465,401	67.4	17,361	1,797,852	33.7	84,468	273,441
Rhode Island	979,367	464,572	969,058	903,567		20.5	494,172	46,205	405,569	10.8		33,755	3.5	29,596	25,248
South Carolina	2,729,583	1,385,477	1,994,909	1,990,668		168.4	1,054,855	671,572	366,849	97.7	20,920	56,214	1.3	46,423	962,413
South Dakota	3,005,739	1,523,821	2,814,888	2,305,738	20,017	440.6	698,768	580,520	106,594	183.3	92,267	931,740	150.1	27,213	465,471
Tennessee	4,246,309	2,105,453	4,010,320	3,388,831		171.0	1,256,704	689,207	471,096	28.1	146,355	827,297	33.7	21,916	807,060
Texas	11,588,643	6,858,253	11,184,806	10,709,724		972.5	3,157,663	811,259	2,309,404	248.7	52,785	923,283	73.8	14,874	3,625,566
Utah	2,367,205	1,066,345	2,757,590	2,279,074	365,500	237.8	695,401	84,632	410,100	57.9		82,373	3.9	3,499	208,373
Vermont	928,184	466,042	973,160	912,749	28,464	47.9	277,219	10,670	249,114	13.9		142,265	5.3	4,766	46,199
Virginia	3,708,379	1,882,693	3,561,573	3,347,008		143.7	1,028,959	76,416	890,514	49.9	107,130	617,288	32.2	177,825	374,892
Washington	3,057,934	1,553,206	2,594,663	2,578,369		95.6	1,259,658	434,929	784,260	28.1	30,664	151,075	4.5	13,972	617,871
West Virginia	2,013,405	1,140,167	1,947,968	1,876,440	60,892	71.2	543,180	111,669	414,619	20.0		287,325	9.2	25,296	377,331
Wisconsin	4,697,518	1,865,947	4,441,736	4,321,782	3,324	213.1	802,396	239,441	457,852	42.8	50,000	663,176	26.2	86,294	741,595
Wyoming	2,250,663	1,692,907	2,290,223	2,025,440	67,583	469.8	1,107,512	209,202	872,144	132.2		499,822	100.4	16,020	253,358
District of Columbia															
Hawaii	1,683,956	598,778	353,056	253,748		12.4	1,826,261	1,428,169		27.2				2,040	598,778
TOTALS	185,426,464	94,483,878	174,691,881	152,642,509	3,286,183	11,605.6	73,655,311	27,991,642	35,144,886	3,462.1	2,312,520	25,762,806	1,691.9	2,479,793	30,290,003

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JANUARY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,389,928	$1,054,361	$1,094,208	$1,094,205		30.6	$1,212,243	$1,139,050	$73,193	35.2		$65,845	1.9	$156,670	$925,922
Arizona	807,982	305,191	624,318	616,215	$6,592	12.3	20,819	500	15,124	.7	$149,322	15,894	1.1	41,946	267,582
Arkansas	1,964,534	857,025	1,380,209	1,280,982		39.5	555,758	555,431		5.5	101,076	117,754	4.6	27,045	739,271
California	4,213,986	2,219,360	3,901,155	3,402,117		46.7	1,332,468	789,009	301,900	10.3		320,632	6.8	22,859	1,596,828
Colorado	1,718,633	190,000	1,769,448	1,704,869	13,406	35.9	5,716		5,716	1.2		170,878	2.0	13,764	
Connecticut	802,407	426,500	802,159	798,075		10.2	144,632		144,632	1.2				4,332	281,867
Delaware	477,680	230,849	474,326	466,045		7.4	54,180		54,180	.7	4,323		.7	7,313	176,669
Florida	1,410,008	501,200	1,244,727	1,004,216		13.2	470,605	399,716	70,889	7.4		24,263	.6	6,075	406,048
Georgia	2,724,620	1,278,373	1,335,128	1,333,015		57.2	897,741	894,100	3,641	14.4	286,820	148,880	10.7	210,684	1,125,852
Idaho	1,197,829	321,126	1,159,884	1,121,373	2,643	19.4	67,654	45,372	22,282	1.4		2,156	.1	31,084	294,045
Illinois	7,476,075	2,515,835	5,819,861	5,730,675		62.9	1,777,874	1,681,538	96,336	9.1	57,163	771,430	6.7	6,698	1,648,069
Indiana	4,287,050	2,035,585	2,853,955	2,825,775		61.3	1,216,466	1,216,316		10.1	216,396	233,401	6.5	28,563	1,802,184
Iowa	2,614,472	1,311,000	1,935,688	1,839,364	6,655	53.3	727,154	629,108	63,367	9.2	146,000	415,285	10.3		825,693
Kansas	2,522,401	1,279,419	2,105,658	2,085,677	2,443	38.6	871,787	410,998	315,936	5.7	25,726	961,040	10.4		
Kentucky	1,927,828	954,578	1,352,542	1,332,461		30.8	589,028	495,167	89,533	4.1	94,506	240,182	5.9	5,695	624,863
Louisiana	1,718,577	744,560	671,616	670,482		17.6	902,654	853,474	20,000	10.3	181,597	317,818	9.5	13,024	406,742
Maine	909,878	490,045	821,221	815,428		16.4	38,605	38,605		.4		111,539	.8	55,845	378,506
Maryland	891,132	452,515	388,284	384,134		4.1	911,650	98,129		.4	54,838		.2	354,031	452,515
Massachusetts	5,007,199	847,600	1,915,107	1,873,562		12.3	3,073,328	2,996,104	52,248	5.4		196,438	1.3	137,533	598,913
Michigan	3,500,638	1,613,142	3,198,155	3,070,806	101,950	39.0	1,356,500	412,750	931,250	8.8	14,950	370,850	9.8	2,131	209,092
Minnesota	3,719,143	1,421,494	3,243,807	3,018,187	194,608	108.5	368,938	155,856	204,882	10.7		32,618	4.7	545,100	989,386
Mississippi	1,744,669	885,056	564,834	552,374		20.0	716,195	653,171	63,024	23.6	314,318	69,289	8.9	224,807	752,743
Missouri	4,019,501	1,617,451	2,124,406	2,054,266		48.7	1,981,693	1,834,510	101,345	12.4	53,877	86,105	2.3	76,848	1,430,001
Montana	1,115,962	113,092	1,059,272	1,056,876		32.4	65,264	34,716	5,994	4.5	8,796	33,230	3.2	15,574	73,868
Nebraska	1,957,240	991,091	2,072,077	1,953,553	104,535	35.7	247,684		247,684	3.5		508,365	10.5	3,687	130,508
Nevada	500,051	100,000	502,397	483,944		8.8	65,438	16,107	49,331	1.5		1,000			49,668
New Hampshire	706,640	242,366	726,187	668,776	54,054	15.9	131,823		131,613	3.0				37,864	56,699
New Jersey	3,117,921	1,809,500	2,383,244	2,284,751		20.0	1,293,051	813,546	334,714	6.6		81,070	.4	19,625	1,393,716
New Mexico	1,674,158	529,506	1,379,467	1,379,467		31.3	373,264	193,167	180,097	8.9		69,432	1.7	101,524	279,977
New York	8,255,661	3,940,621	6,247,552	5,890,351		53.2	4,170,403	2,296,556	1,708,900	23.5		782,000	5.6	68,753	1,449,721
North Carolina	2,380,573	1,210,236	1,949,871	1,920,950	26,797	73.9	347,120	270,214	33,338	8.5	161,387	199,017	6.5	28,022	951,084
North Dakota	1,451,112	734,742	1,028,561	1,024,706		43.4	197,078	121,828	75,250	7.2	277,222	90,732	20.3	27,356	568,760
Ohio	4,335,686	2,359,503	4,561,839	4,047,107	15,000	57.8	446,280	226,500	219,780	5.3		1,015,240	13.9	62,079	1,109,484
Oklahoma	2,304,200	1,171,295	1,753,096	1,723,984		38.3	635,412	535,691	95,756	9.7	1,326	294,807	3.2	43,198	780,732
Oregon	1,526,724	867,977	1,495,885	1,472,859		27.8	112,979		112,979	1.6	47,611	217,689	7.3	6,254	537,309
Pennsylvania	4,854,988	2,397,703	3,449,546	3,248,347	66,031	54.7	1,838,894	1,512,490	244,527	15.8	32,000	1,457,065	15.0	62,151	630,079
Rhode Island	579,625	255,000	527,914	527,015		7.4	36,001		36,001	.6				52,609	218,999
South Carolina	1,364,791	692,738	862,541	861,123		28.9	387,514	383,370	4,144	14.9	42,750	17,957	.7	77,549	670,638
South Dakota	1,502,870	761,911	1,046,266	1,046,266		35.0	111,901	111,732	169	5.5	82,065	37,522	6.4	262,806	724,221
Tennessee	2,123,155	1,121,790	1,548,267	1,542,456		22.8	580,587	475,617	104,970	5.2	94,256	199,446	3.4	10,827	817,373
Texas	6,642,863	1,795,000	4,107,900	4,003,156		104.1	2,441,789	2,274,377	3,122	17.3	254,300	114,196	10.9	111,030	1,677,682
Utah	778,826	533,173	748,473	649,487	65,900	20.2	200,559	124,000	71,000	2.3	5,130	245,000	6.3	209	151,273
Vermont	500,509	240,611	461,194	441,585		12.9	112,923	58,924	47,000	2.4		78,000	1.1		115,611
Virginia	2,008,458	941,347	1,305,950	1,236,736	39,687	25.2	839,582	458,925	189,433	6.2	32,213	168,480	3.9	280,585	543,748
Washington	1,977,260	776,603	1,949,664	1,931,928		32.4	215,895		215,895	5.9	36,458	244,141	6.9	8,874	316,567
West Virginia	1,342,270	570,085	875,139	861,846	13,293	16.1	493,653	453,304	14,816	5.3		16,863	.6	27,120	525,113
Wisconsin	2,596,143	1,293,455	2,515,141	2,455,395	15,575	52.3	382,698	116,488	241,393	7.0		194,881	4.5	24,260	841,606
Wyoming	1,125,332	22,877	1,027,545	1,025,209		22.3	107,334	100,123	6,629	2.6		10,287	.7		5,961
District of Columbia	968,235	243,460	933,385	704,306	229,079	6.5	250,164	250,164		.2				13,766	14,381
Hawaii															
TOTALS	115,737,423	49,278,547	87,299,069	83,516,465	958,248	1,665.2	35,378,978	26,126,743	7,004,013	363.2	2,776,426	10,748,717	238.8	3,317,769	30,567,569

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JANUARY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064.960	$ 697,830	$ 697,830		46.0	$ 1.442,743	$ 1,300,029	$ 142.714	109.3		$ 348,192	22.1	$ 34,593	$ 574,055
Arizona	525.423	998,032	530,237	517.610		42.3	306,633	7.813	260.093	21.5		81,538	8.7		656,401
Arkansas	1.449,634	857,024	925,387	923,201		124.8	518,293	447.626	70,182	40.4	$ 5.473	102,484	28.2	73.334	684,358
California	3.480,440	1,999.203	3.436,627	2.881,768		161.2	1,110,649	598,046	361.800	29.4		424,856	12.9	626	1,212,547
Colorado	1,718,632	871,502	1,721,308	1,608.632	$ 11,800	170.7	933,719	110,000	419,020	154.4		82,520	3.6		358,162
Connecticut	659,120	420,868					887,796	659,120	222,880	19.0		11,129	.4		186,859
Delaware	448.864	230.849	285,891	218.551	63,291	24.1	390.690	228.623	127.893	35.6				1,690	39,665
Florida	1,302,815	1,043,543	1,280,232	1.274.186		77.5	358.943		358,943	21.0		73.559	1.9	28,630	611,041
Georgia	2,320.973	1,273,373	1,159,297	1,158.044		81,2	932,462	923.310	9.152	72.2	79.928	183.703	10.8	159.691	1,085.519
Idaho	1,121.562	824,450	1,307,631	1,118,961	60,449	156.5	382,738		377.447	42.5		51.700	6.8	2,601	334,854
Illinois	5.652,228	3.345.525	1,901,589	1,888.614		119.0	4,567,887	3.648.860	919,027	258.6	99.933	2,288,358	102.7	14,821	138,140
Indiana	731,872	209,900	404,572	404,572		44.2	272,102	272.102		40.7	48.450	16,356	3.5	6.749	193,544
Iowa	2.413,358	1,590.000	2,064,021	1,932,895	67,450	295.1	1,129.334	424.850	550,100	192.2		724.150	167.7	55,613	248,300
Kansas	2.522,401	1,279,419	1,945,421	1.876.032	65.467	202.0	1,172,290	637.717	534,573	72.8	8,652	679,379	42,2		
Kentucky	1,837,926	1.336,409	1,802.617	1,724,078	16,263	210,0	712,944	85.833	606,379	74.5	21,369	279,000	51.1	6,645	434,767
Louisiana	1.398,862	838,953	950,765	949.942		45.1	326,143	323,941		14.3	123.793	334,474	24.5	1.185	504,479
Maine	842,479	427,897	1,060,215	835,952	146,555	90.4	282.470	5,000	256,412	21.4		16.526	.7	1,527	8,404
Maryland	891.132	1,067.934	661,949	640,929		49.8	447,351	224,250	223,101	25.5	20,419	413,720	12.1	5.534	431,113
Massachusetts	488,185	870.000	469,741	469,741		15.2						49,403	2.0	18.444	820,597
Michigan	3,184,057	1.613,142	2,867,212	2,837.586	16,400	205.6	1,032,877	341,727	676 250	41.1		447.450	27.6	4,744	473,042
Minnesota	2,376,415	1,361,813	2,314,276	2,218.135	63,116	242.8	789,631	141,133	503,698	98.5		479,720	50.3	17,148	315.279
Mississippi	1,744,669	354,023	693.388	693,388		86.2	767,895	767,895		61.7	187.185		12.8	96,201	354,023
Missouri	2.923,273	2,423,863	2,848,374	2.667,484	106,368	584.5	699.562	158.005	496.304	177.3	77.547	594,427	84.2	20.238	1,226.765
Montana	1,859,937	942,434	1,814,177	1,813.058		226.0	216,652		216.652	12.8		343.679	35.2	46.879	382.103
Nebraska	1,957,240	991,091	2.078,186	1.956,356	118,655	339.8	470,756		470.756	93.9		321,529	55.3	884	80.151
Nevada	1,136,479	852.000	1.232,741	1,112,162	75,272	140.1	281,012		281,012	25.9		20.000	10.0	24,317	475,716
New Hampshire	477,460	242.365	521,263	476.963		25.6	85,607		82.590	4.6		57.479	3.4	497	102,296
New Jersey	55,099	460,000	56,528	55,099		.5									460.000
New Mexico	1.272.129	735.425	1.226,434	1,226,434		207.4	357.791	35.000	322,791	52.2	10.695	194,235	15.9		218,399
New York	3,608,768	3,865,850	3.320.536	2,957,818	28,200	83.8	3.709,270	625.700	2,284,350	165.6		1,247,368	120.9	25.250	305,932
North Carolina	2,380.573	1.590.637	2,006.317	2.005.539		212.4	979.356	364.701	608.564	102.4		391.717	36.7	10.333	590,355
North Dakota	1.451,112	734,741	895,842	895,842		283.1	274,969	274,969		70.3	220,451	189,033	118.9	59.850	545,709
Ohio	3.871,148	1.966,253	4,055,935	3.767,315	2,100	297.9	515.010	73.810	439.200	78.1		384,170	22.4	30.023	1.140.783
Oklahoma	2,304,199	1,171,295	1,580.960	1,493,471		206.0	1,186,172	780.467	304,896	76.8	28.270	447.179	29.2	1,991	419,219
Oregon	1,526.724	777.096	1,709.157	1,507,198	23,904	112.0	452,348	19,526	392,441	35.3		233,254	16.7		127,497
Pennsylvania	7,344,822	2.639,003	6,397,236	6,177,827	81,002	542.8	2,843,900	1,162,995	1,646,825	204.8	4.000	686,002	18.0		225,174
Rhode Island	439,716	295,000	414,250	404,768		33.2	39.789		39.789	1.0		222.350	5.6	34,948	32.860
South Carolina	1,364,791	692,739	1,116.509	1,060,256	56,253	119.6	647,405	255,654	370.646	89.0		265,840	33.3	48,882	
South Dakota	1,502,870	761,911	1,164,126	1,115,952	48,151	330.1	331,687	331,687		97.1	55.231	94,193	52.5		619,567
Tennessee	2,123,155	1,075.748	1,241.068	1,210,241		102.6	1,122,787	834,756	288,031	61.9	4,503	149,662	4.9	73.654	638,055
Texas	6.012,518	3,638.000	5,876,171	5,450,782		750.6	1,392.548	500,417	840.893	71.6	43.305	235,713	38.0	18,014	2.561.394
Utah	1,048.677	533,173	1,185.881	955.732	114,800	185.6	238,999	92,945	108.000	40.4		185.373	32.4		125,000
Vermont	438,880	241,354	473,091	437,162	16.569	37.2	118,931		113,646	8.4		94,956	7.0	1,718	16,183
Virginia	1.699,920	941,347	1.602.318	1,533,987	8.753	210.4	269,543	107,265	151,095	13.5	21.527	252,555	22.9	37,141	528.943
Washington	1,080,673	776,603	990,303	969.480		62.6	430,041	103.666	326.375	37.0		234.253	11.2	7.526	215,975
West Virginia	1.118,559	570,083	733.349	701,137		41.9	359.084	359,084		15.1	25,237	178,802	5.5	33,101	391,281
Wisconsin	2,431.220	1.782,435	2,323,522	2,156,632	48.583	170.4	491.465	202,460	232,848	14.5	68,000	303,365	24.7	4,128	1,137,638
Wyoming	1.125,332	571,928	1.077,254	1.058,834		148.5	90.037		90,035	12.3	30.935	224,994	37.4	35,563	256,899
District of Columbia	950,234	730,382	1,071,502	931,582	139.920	8.7	234,139		234,139	2.6		147,150	1.6	18,651	209,173
Hawaii	187,106	351,000	177,718	177,718		4.9								9,388	351,000
TOTALS	92,836.113	56,237.575	77,670,954	73,147,476	1,379,321	7,957.9	36.604,450	17.430,982	16,961,542	3,011.0	1,184.903	14.787,495	1436.4	1,072,752	23,109,217

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2. AND 3.

AS OF JANUARY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 7,017,804	$ 4,628,027	$ 35,889	371.2	$ 4,981,444	$ 3,415,817	$ 750,118	278.1	$ 58,042	$ 987,877	55.8	$ 268,247	$ 2,485,958
Arizona	5,211,960	2,641,935	5,500,699	4,830,848	55,617	345.3	1,303,243	166,037	1,064,402	90.4	153,977	214,311	25.5	61,098	1,307,605
Arkansas	6,748,335	3,428,049	5,197,072	4,510,954	137,101	316.3	2,375,515	1,884,376	264,254	81.9	146,112	1,064,465	80.6	206,893	1,962,229
California	15,607,354	7,932,206	16,418,562	13,112,487		485.2	5,620,799	2,463,259	1,545,300	91.3		1,687,438	59.2	31,608	4,699,468
Colorado	6,874,530	3,486,006	7,290,855	6,680,459	375,966	381.1	2,624,179	126,425	2,074,075	240.4	53,881	345,947	17.4	13,764	689,998
Connecticut	2,865,740	1,454,868	1,422,697	1,416,280		21.0	2,534,404	1,445,129	820,911	45.7		165,229	2.2	4,332	468,727
Delaware	1,819,088	923,395	1,638,107	1,558,582	63,291	64.9	910,188	228,623	632,213	51.6	4,323		.7	27,560	227,891
Florida	5,231,834	2,661,343	5,370,464	4,369,941		194.1	1,572,382	749,980	702,878	55.8	3,231	609,780	23.5	108,682	1,348,684
Georgia	10,091,185	5,113,491	6,135,781	5,943,644		391.2	3,358,958	3,064,045	294,913	163.3	578,703	1,372,889	79.1	504,793	3,445,689
Idaho	4,486,249	2,277,486	4,619,786	4,225,307	160,418	360.1	984,086	216,522	750,078	72.0		135,128	20.2	44,419	1,231,863
Illinois	17,570,770	8,921,401	9,499,158	9,386,344		214.2	9,386,465	7,945,535	1,440,930	306.7	193,141	3,883,606	127.8	45,751	3,596,864
Indiana	10,037,843	5,088,963	6,325,180	6,283,326		208.3	3,404,924	3,404,034		88.8	315,171	1,189,144	127.8	35,312	3,899,819
Iowa	10,055,660	5,118,361	8,853,937	8,384,103	116,225	625.8	3,646,200	1,434,558	1,927,743	324.3	146,000	1,685,853	202.6	90,999	1,388,539
Kansas	10,089,604	5,117,675	9,358,020	8,898,530	230,850	777.5	3,469,744	1,105,115	2,219,775	230.4	34,379	2,661,726	119.3	51,580	5,324
Kentucky	7,517,359	3,818,311	6,782,097	6,415,520	49,834	484.7	1,908,553	841,654	989,686	128.3	225,352	874,308	94.3	34,833	1,304,483
Louisiana	5,828,591	2,963,932	3,378,656	3,372,920		136.6	3,062,369	2,082,889	426,070	36.4	349,773	1,327,199	45.8	23,009	1,210,663
Maine	3,369,917	1,711,586	3,234,295	2,968,672	146,555	150.5	1,126,612	283,061	822,493	35.2		325,467	8.3	118,185	417,071
Maryland	3,564,527	1,810,058	1,841,856	1,803,195	3,843	69.0	2,245,878	1,093,839	338,518	45.9	114,392	511,450	14.0	553,101	956,248
Massachusetts	6,597,100	3,350,474	3,793,878	3,359,383		65.0	3,566,882	3,048,791	441,294	14.6		678,947	6.5	188,927	2,230,233
Michigan	12,736,227	6,452,568	10,838,181	10,604,709	118,350	468.0	5,102,302	2,102,677	2,957,425	151.4	14,950	2,403,225	97.6	13,891	973,568
Minnesota	10,656,569	5,425,551	11,164,300	9,567,651	1,437,787	1201.2	2,080,134	476,045	1,385,689	253.9		830,170	97.8	612,873	1,771,905
Mississippi	6,978,675	3,540,227	5,249,371	3,432,371		310.8	3,951,269	2,555,662	477,221	220.3	520,668	856,658	60.9	469,974	2,206,348
Missouri	12,180,306	6,173,740	9,625,656	8,839,778	106,368	821.1	4,851,513	2,806,243	1,656,386	258.3	425,062	1,445,958	107.2	109,222	2,965,028
Montana	7,439,748	3,769,734	8,140,380	7,305,046	190,457	653.0	1,934,707	38,846	1,802,351	206.4	8,796	1,182,242	85.4	87,060	594,684
Nebraska	7,828,961	3,964,364	9,263,087	7,802,747	265,595	747.1	2,016,446	21,644	1,672,259	155.7		1,779,780	117.2	4,571	246,730
Nevada	4,545,917	2,302,356	4,596,856	4,332,283	151,311	417.6	1,080,110	108,055	972,055	128.3	34,558	35,755	12.6	71,021	1,143,234
New Hampshire	1,909,839	969,462	1,886,134	1,758,128	54,054	52.4	643,002	79,730	538,983	18.8		190,991	4.7	71,981	185,435
New Jersey	6,346,039	3,220,879	4,151,613	4,032,158		52.1	2,781,150	2,109,646	359,633	22.0	175,941	184,069	3.0	28,294	2,677,177
New Mexico	5,792,935	2,941,700	5,635,221	5,366,849	124,443	536.2	1,809,683	246,096	1,563,586	152.7	78,466	263,667	22.5	101,524	990,004
New York	22,330,101	11,327,921	19,766,023	17,264,358	81,200	347.3	15,512,601	4,932,326	6,384,850	323.9		2,307,218	135.5	133,417	2,554,653
North Carolina	9,522,293	4,840,941	8,344,520	7,484,842	131,756	862.7	2,660,293	1,281,880	961,456	235.2	415,370	855,213	92.5	340,201	2,892,516
North Dakota	5,804,448	2,938,967	5,057,459	4,585,989	39,051	1334.2	801,559	450,569	291,196	194.9	537,985	756,534	403.4	229,906	1,852,185
Ohio	15,484,592	7,865,012	16,100,528	14,875,571	17,100	548.9	2,532,160	318,330	2,019,440	123.1		3,099,461	63.2	290,691	2,729,011
Oklahoma	9,216,798	4,685,180	6,993,741	6,798,731		517.1	3,363,522	2,074,397	1,155,630	156.0	288,573	1,779,507	87.4	55,097	1,750,043
Oregon	6,106,896	3,097,814	6,539,716	5,997,344	23,904	322.8	1,712,221	33,145	1,581,694	85.7	47,611	535,295	32.2	28,796	956,921
Pennsylvania	18,891,004	9,590,788	15,379,822	14,765,488	164,423	717.4	8,593,441	3,925,537	4,356,754	288.0	53,361	3,940,918	66.7	146,619	1,128,694
Rhode Island	1,998,708	1,014,572	1,911,223	1,835,350		61.1	569,962	46,205	481,359	12.5		256,106	9.2	117,153	277,107
South Carolina	5,459,165	2,770,954	3,973,959	3,912,046	56,253	316.9	2,089,774	1,310,595	741,639	201.6	63,669	340,010	35.3	172,854	1,633,051
South Dakota	6,011,479	3,047,643	5,025,280	4,467,956	68,168	805.7	1,142,356	1,023,940	106,762	285.9	229,564	1,063,454	209.1	290,019	1,809,259
Tennessee	8,492,619	4,302,991	6,799,655	6,141,528		296.4	2,960,078	1,999,580	864,098	95.2	245,114	1,176,406	42.0	106,397	2,262,488
Texas	24,244,024	12,291,253	21,168,878	20,163,662		1827.2	6,991,999	3,586,052	3,153,418	337.7	350,391	1,273,192	122.6	143,918	7,864,642
Utah	4,194,708	2,132,691	4,691,944	3,884,292	546,200	443.6	1,134,959	301,577	589,100	100.6	5,130	512,746	42.6	3,708	484,646
Vermont	1,867,573	948,007	1,907,445	1,791,495	45,033	98.0	509,072	69,594	409,760	24.7		315,221	13.4	6,484	177,993
Virginia	7,416,757	3,765,387	6,469,841	6,117,731	48,440	379.2	2,138,084	642,605	1,231,042	69.6	160,869	1,038,323	59.0	495,551	1,447,583
Washington	6,115,867	3,106,412	5,534,631	5,479,778		190.6	1,905,594	538,595	1,326,530	71.0	67,122	629,468	22.6	30,372	1,150,414
West Virginia	4,474,234	2,280,335	3,556,455	3,439,422	74,185	129.2	1,395,917	924,058	429,435	40.4	25,237	482,990	15.3	85,517	1,293,725
Wisconsin	9,724,881	4,941,837	9,280,399	8,933,809	67,483	435.8	1,676,559	558,390	932,092	64.4	118,000	1,161,423	55.4	114,682	2,780,839
Wyoming	4,501,327	2,287,712	4,395,022	4,109,483	67,583	640.6	1,304,883	309,326	968,808	147.0	30,935	735,104	138.6	51,583	516,218
District of Columbia	1,918,469	973,842	2,004,887	1,635,888	368,999	15.2	484,303	250,164	234,139	2.8		147,150	1.6	32,417	223,554
Hawaii	1,871,062	949,778	530,773	431,465		17.3	1,826,261	1,428,169		27.2				11,428	949,778
TOTALS.	394,000,000	200,000,000	339,661,904	309,306,470	5,623,752	21,228.7	145,638,739	71,549,367	59,110,441	6,836.3	6,273,849	51,299,018	3,367.1	6,870,314	83,966,789

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